AGARD-LS-201

AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT
7 RUE ANCELLE, 92200 NEUILLY-SUR-SEINE, FRANCE

AGARD LECTURE SERIES 201

Environmentally Safe and Effective Processes for Paint Removal

(Procédés efficaces et écologiques pour l'enlèvement des peintures)

This publication was prepared at the request of the Structures and Materials Panel and under the sponsorship of the Consultant and Exchange Programme of AGARD and will be presented on 27-28 April 1995 in Lisbon, Portugal, 1-2 May 1995 in Eskisehir, Turkey, and 4-5 May 1995 in Ottobrunn, Germany.

NORTH ATLANTIC TREATY ORGANIZATION

Published April 1995

Distribution and Availability on Back Cover

Canada	Groupe
Communication	Communication
Group	Canada

Printing Services — Services d'imprimerie

45 Sacré-Coeur Blvd.
Hull, Québec
K1A 0S7

45, boul. Sacré-Coeur
Hull (Québec)
K1A 0S7

April 20, 1995

TO THE RECIPIENT OF AGARD PUBLICATION LS-201:

Please be advised that the title for Paper #10 does not appear on the first page of the paper (page 10-1). The title of this paper is:

Selective Chemical Stripping

Sincerely,

K Edwards
Kelly Edwards
A/Project Manager
AGARD Publications

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT
7 RUE ANCELLE, 92200 NEUILLY-SUR-SEINE, FRANCE

AGARD LECTURE SERIES 201

Environmentally Safe and Effective Processes for Paint Removal

(Procédés efficaces et écologiques pour l'enlèvement des peintures)

This publication was prepared at the request of the Structures and Materials Panel and under the sponsorship of the Consultant and Exchange Programme of AGARD and will be presented on 27-28 April 1995 in Lisbon, Portugal, 1-2 May 1995 in Eskisehir, Turkey, and 4-5 May 1995 in Ottobrunn, Germany.

North Atlantic Treaty Organization
Organisation du Traité de l'Atlantique Nord

The Mission of AGARD

According to its Charter, the mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

— Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community;

— Providing scientific and technical advice and assistance to the Military Committee in the field of aerospace research and development (with particular regard to its military application);

— Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

— Improving the co-operation among member nations in aerospace research and development;

— Exchange of scientific and technical information;

— Providing assistance to member nations for the purpose of increasing their scientific and technical potential;

— Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Programme and the Aerospace Applications Studies Programme. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

Participation in AGARD activities is by invitation only and is normally limited to citizens of the NATO nations.

Published April 1995

ISBN 92-836-1017-2

Printed by Canada Communication Group
45 Sacré-Cœur Blvd., Hull (Québec), Canada K1A 0S7

Abstract

Environmentally Safe and Effective Processes for Paint Removal

Paint stripping and repainting of aircraft surfaces are required periodically during the operating lifetime of an aircraft. Historically, paint removal has been achieved using chemical strippers, involving materials which contain toxic components and which create hazardous working conditions. The process generates large amounts of hazardous waste from the chemicals used. Alternative methods for aircraft paint removal are now being investigated within the NATO nations with regard to their environmental safety and effective application. These processes include: Plastic Media Blasting, Wheat Starch Dry Media Blasting, Carbon Dioxide Pellet Blasting, Sodium Bicarbonate Blasting and Thermal Decomposition Methods (Laser, Flash Lamps/Carbon Dioxide). The Lecture Series will review these current state-of-the-art alternative methods with regard to environmental effects and related health hazards, costs, process controls, practicality of operation and their effects on properties of aircraft structural materials.

Abrégé

Procédés efficaces et écologiques pour l'enlèvement des peintures

L'enlèvement des peintures et la remise en peinture des surfaces extérieures d'un aéronef sont demandés périodiquement tout au long de la vie opérationnelle de l'appareil. Traditionnellement, ces opérations sont réalisées à l'aide de décapants chimiques qui contiennent des ingrédients toxiques, et qui créent, par conséquent, des conditions de travail dangereuses. Le procédé génère des volumes importants de déchets nocifs.

Des méthodes alternatives pour l'enlèvement des peintures aéronautiques sont en cours d'examen au sein des pays membres de l'OTAN du point de vue du danger qu'ils représenteraient pour l'environnement et de l'efficacité de leur application. Ces procédés comprennent: le décapage à sec par projection de grenailles plastiques, le grenaillage à boulettes de dioxyde de carbone, le grenaillage au bicarbonate de soude et les méthodes basées sur la décomposition thermique (laser, feux à éclair/dioxyde de carbone).

Ce cycle de conférences fera le point de ces méthodes alternatives avancées actuelles en ce qui concerne leur impact écologique et les risques sanitaires associés, les coûts, les contrôles en cours de fabrication, la faisabilité de l'opération et les conséquences de l'adoption de ces méthodes pour les caractéristiques des matériaux structuraux aéronautiques.

List of Authors/Speakers

Lecture Series Director: Dr. Jeffrey WALDMAN
Naval Air Warfare Center
Aircraft Division Warminster
4.3.4.2. M/S 08 (Code 6063)
P.O. Box 5152
Warminster, PA 18974-0591
USA

Authors/Speakers

Dr. Terry FOSTER
Head Materials Technology
Esquimalt Defence Research Detachment
FMO Victoria
Victoria, BC Canada
V0S 1B0
CANADA

Mr. Olivier MALAVALLON
Aérospatiale
Direction des Etudes
A/DET/CG-MP
Toulouse Est.
316 route de Bayonne
31060 Toulouse Cedex 03
FRANCE

Author

Mr. S. VISAISOUK
Ice Blast International Corp.
627 John St.
Victoria, BC
CANADA V8T 1T8

Contents

	Reference
Abstract/Abrégé	iii
List of Authors/Speakers	iv
Introduction by Dr. Jeffrey WALDMAN	I
Overview of Paint Removal Methods by Dr. Terry FOSTER	1
Paint Removal Principles by Mr. Olivier MALAVALLON	2
Background to Plastic Media Blasting by Dr. T. FOSTER	3
Dry Media Blasting with Wheat Starch by Mr. O. MALAVALLON	4
Water Blasting Paint Removal Methods by Dr. T. FOSTER	5
Paint Removal and Surface Cleaning Using Ice Particles by Dr. T. FOSTER and Mr. S. VISAISOUK	6
Stripping with Dry Ice by Mr. O. MALAVALLON	7
Aquastrip by Mr. O. MALAVALLON	8
Stripping by Laser by Mr. O. MALAVALLON	9
Selective Chemical Stripping by Mr. O. MALAVALLON	10
Facilities used for Plastic Media Blasting by Dr. T. FOSTER	11
Treatment of Plastic Media Waste by Dr. T. FOSTER	12
Bioremediation of Wheat Starch Media Waste by Mr. O. MALAVALLON	13
Operational Parameters and Material Effects by Dr. T. FOSTER	14
Process Evaluation by Mr. O. MALAVALLON	15
Standardization Work by Mr. O. MALAVALLON	16
Future Prospects by Mr. O. MALAVALLON	17
Bibliography	B

Introduction

Paint removal and repainting of aircraft surfaces are required periodically during the operating lifetime of an aircraft. Historically, paint removal has been achieved using chemical paint removal methods. These methods use materials which contain toxic components and which create hazardous working conditions. These processes also generate large amounts of hazardous waste from the chemicals used.

Alternative methods for aircraft paint removal that are environmentally safe are now being investigated within the NATO nations. These processes include: Plastic Media Blasting and other abrasive blasting methods (Wheat Starch, Water Jet, Ice Particles, Carbon Dioxide Pellets, Sodium Bicarbonate) as well as Thermal Decomposition Methods (Laser, Flash Lamps/Carbon Dioxide).

In October 1992 the Structures and Materials Panel of AGARD held a workshop on Environmentally Safe and Effective Processes for Paint Removal from aircraft. The purpose of the workshop was to review the state-of-the-art of the new technologies for paint removal and their effects on the properties of aircraft structural materials. The practicality of operation, environmental effects, cost and process controls were also discussed in that these factors strongly influence the implementation of alternate paint removal processes.

As a result of the workshop, it was decided to present a Lecture Series on Environmentally Safe and Effective Processes for Paint Removal for aircraft. Two experts in the field (Dr. T. Foster and Mr. O. Malavallon) will present a series of lectures on this subject. The lectures will cover in detail the principles of paint removal and various environmentally safe paint removal processes including plastic media blasting and other abrasive blast removal methods as well as environmentally safe thermal and chemical paint removal processes. The treatment of waste disposal and work on standardization of the various alternate paint removal processes will also be presented. The Lecture Series will review these current state-of-the-art alternative paint removal methods with regard to environmental effects and related health hazards, costs, process controls, practicality of operation and their effects on properties of aircraft structural materials.

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

OVERVIEW OF PAINT REMOVAL METHODS

Dr. Terry Foster
Esquimalt Defence Research Detachment
FMO Victoria
Victoria, B.C., Canada V0S 1B0

SUMMARY

As an introduction to environmentally safe and effective methods of paint removal, the following is an overview of the various methods available. Many of the methods introduced in this paper will be discussed in further detail during this lecture series. The purpose of this overview is to introduce the various paint removal methods available.

1. INTRODUCTION

With the introduction of strict environmental regulations governing the use and disposal of methylene chloride and phenols, major components of chemical paint strippers, there have been many new environmentally safe and effective methods of paint removal developed. The new methods developed for removing coatings from aircraft and aircraft components include: mechanical methods using abrasive media such as plastic, wheat starch, walnut shells, ice and dry ice, environmentally safe chemical strippers and paint softeners, and optical methods such as lasers and flash lamps.

Each method has its advantages and disadvantages, and some have unique applications. For example, mechanical and abrasive methods can damage sensitive surfaces such as composite materials and strict control of blast parameters and conditions are required. Optical methods can be slow, leaving paint residues, and chemical methods may not remove all of the coating or require special coating formulations to be effective.

2. PLASTIC MEDIA - VARIOUS TYPES

Plastic media was the original media developed as a replacement for chemical strippers. This media will be the focus of a series of lectures in this series and only a brief summary will be given here.

Plastic media is made from a variety of polymeric materials, depending on the hardness of the blast media required, and is produced in a variety of grit sizes. The main plastic media are based on acrylic, urea formaldehyde, melamine-formaldehyde, polyester and polyallyl diglycol carbonate. The properties of the various plastic media are shown in Table 1.

Since its development in the early 1980's, PMB has developed into a process used routinely in many areas of aircraft refinishing, especially military aircraft. The US, Canadian, German and other air forces worldwide have approved some form of plastic media stripping for aircraft. Many studies have been carried on the effects of the various plastic media and the operating parameters (media

TABLE 1 -- BLAST MEDIA PROPERTIES

MEDIA	CHEMICAL COMPOSITION	HARDNESS (Moh scale)	DENSITY (g/cm^3)
Type I	Polyester	3.0	1.25
Type II	Urea Formaldehyde	3.5	1.5
Type III	Melamine Formaldehyde	4.0	1.5
Type IV	Phenol Formaldehyde	3.5	1.5
Type V	Acrylic	3.5	1.2
Type VI	Polyallydiglycol carbonate	3.0	1.3

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

flow rate, media type, blasting pressure and standoff distance) on material properties of aluminum, titanium, and various composite materials (esp. graphite epoxy composites).

3. STARCH BASED MEDIA

Wheat starch blasting media will also be discussed in much more detail in subsequent lectures and only a brief summary will be included here. Wheat starch was developed by Ogilvie Mills Ltd (now a subsidiary of CAE Canada Ltd.), Montreal, Canada as a biodegradable, non-toxic, non-petroleum based, natural polymer abrasive grit for paint removal.

Wheat starch has several advantages over conventional plastic media. This medium is softer than Type II or Type V media and thus the possibility of damage to delicate substrates is reduced. It is much easier to remove one coating layer at a time with wheat starch than with other plastic media. Wheat starch is a natural material and there are minimal disposal problems.

Wheat starch is under consideration by the CF as a possible blasting media. Research is currently under way to investigate the parameters necessary for efficient paint removal and to determine the benefits of wheat starch over Types V and VI plastic media. Wheat starch is also under consideration for special applications such as stripping decals and removing paint from sensitive substrates, such as Kevlar based materials.

Economic and environmental concerns about the disposal of other types of used media could also bring wheat starch into more serious consideration in the future.

4. LASER PAINT STRIPPING

Laser paint stripping is being investigated as a method of paint removal because it requires no abrasive media that requires disposal and the amount of residue remaining after laser stripping is quite small.

Paint removal by laser radiation is by one or both of two mechanisms, vaporization and combustion. For example, if a stream of air is directed at the painted surface during laser stripping, the paint removal is more efficient than if a stream of inert gas, which prevents combustion, is directed at the paint surface. The stream of air allows the paint to combust as well as vaporize whereas the stream of inert gas only allows the paint to vaporize.

Care must be taken when using laser stripping because the substrate surface can reflect or absorb the laser radiation, and the nature of the surface also affects the rate of paint removal. On an anodized aluminum surface, the radiation from a CO_2 laser is absorbed by the oxide layer and the parameters required to strip paint must be more closely controlled than on a reflective surface such as aluminum metal. After laser paint removal, there is no residual paint film left on the anodized surface whereas there is always a residual paint film left on the aluminum surface. On a reflecting surface, as the paint film is reduced in thickness during laser stripping, the amount of laser energy absorbed by the thin paint film is reduced as more of the radiation is reflected from the substrate surface. At some point, vaporization of the thin paint film no longer occurs.

Laser stripping of a coated carbon steel, which also is a reflecting surface for CO_2 laser radiation, resulted in visual damage to the steel surface. Microscopic examination of the steel surface revealed a change in microstructure to a depth of 150 μm at 800 J/cm^2 and 100 kW/cm^2 of laser energy and power. At lower energy and power, 40 J/cm^2 and 60 kW/cm respectively, no damage was observed but, as with the reflective aluminum, a thin layer of paint remained on the surface.

In practice, laser stripping would require a robotic system to ensure that the partially de-focused laser beam was moved across the surface in a controlled manner to prevent surface damage and to maintain paint removal efficiency. Laser stripping is less costly than chemical stripping.

International Technical Associates in the USA are developing an Automated Laser Paint Stripper

(ALPS). This system will consist of the following eight components:

- Laser
- Robot
- Multi Spectral Camera
- Rastering System
- End Effector or Manipulator
- Waste Management System
- Cell Controller
- Safety System

A pulsed (1000 Hz) CO_2 laser (6 kW) is mounted on a robot (supplied by *Vadeko*) that is track mounted, pedestal type with seven degrees of freedom. The camera is used to decide if the coating has been removed. The rastering system is required to ensure the laser moves around the aircraft and does not dwell for extended periods in one position. The material removed from the aircraft is vacuumed up as it is created and then processed through particle and vapour separators to ensure the waste conforms to local regulations. The cell controller is a computer system (UNIX operating system) interfaced to the robot, laser, waste system and safety system. The safety system meets the requirements for laser and robot operation.

5. WATER BLASTING

Two methods of paint removal using high pressure water have been developed. The first method uses only high pressure (28,000 psi) water and the second method employs medium pressure water blasting (up to 7,250 psi) in combination with paint softeners. Although paint softeners add an extra step in the removal process, lower blasting pressures (7,250 psi) are required to remove coatings. High and medium pressure water blasting offers several advantages:

- water is usually readily available
- inexpensive and easy to handle
- selective stripping feasible
- no storage problems
- readily available technology for treatment and disposal
- readily recyclable
- only paint debris to remove
- low capital investment

5.1 Medium Pressure With Paint Softeners

Medium pressure water jets utilizing chemical softeners is a commercial process owned by *LUFTHANSA* called *AQUASTRIP*. The blast head for this process consists of two nozzles integrated into a rotating head. The head rotates at 2000-6500 rpm and is driven by an impulse from the water jets due to the eccentric alignment of the nozzles. The typical parameters used for this process are:

- maximum operating pressure - 7,250 psi
- water velocity - 320 m/sec
- water flow rate - 20 l/min
- traversal speed - 50 mm/sec
- standoff distance - 30 - 150 mm

The *LUFTHANSA AQUASTRIP* study has shown that up to 60% of all stripping jobs require the use of softeners. The softeners used are most effective with polyurethane coatings and the dwell times must be determined for each coating system. A dwell time of 2-4 hours is normal and a water rinse is used to remove the paint softener prior to water blasting. Two water softeners are currently used: *Turco 1270-5* and *Brent LB2020* and both are based on biodegradable solvents such as benzyl alcohol.

A research program was carried out to determine the effects of the *AQUASTRIP* process on the long term integrity of aircraft structures. These tests showed that the two softeners did not induce pitting or etching of aluminum (2024-T3) components and no degradation of elastomers was observed.

During dynamic operation for over 20 cycles no damage was found to clad or anodized layers but damage to these surfaces could occur if the nozzle was stationary for 5-10 seconds. Cadmium plating on fasteners was not removed by this process. Residual stress measurements using Almen Arc Heights showed deflections of less than 10 µm well below the allowable limit of 150 µm for 2024-T3 aluminum. Fatigue test results indicated that under the above

blast conditions there was no change in the fatigue life of the material.

Water migration during blasting can occur into cavities directly accessible for the water jet. Neutron radiography has shown that intact bonded or sealed surfaces are not affected by the *AQUASTRIP* process. The *AQUASTRIP* process can be quite destructive on seals and the seal removed if the jet is directed at the edge of the sealer.

Use of the *AQUASTRIP* process on composite surfaces requires further refinement and it is recommended that each composite material requires a complete test matrix prior to use of the *AQUASTRIP* process. The application of the paint softeners used in the *AQUASTRIP* process to composite surfaces has been approved by *LUFTHANSA* in prior test procedures.

5.2 High Pressure Water

The USAF (Wright Laboratory, Aeronautical Systems Division (AFMC)) and *United Technologies, USBI Co.* are developing a Large Aircraft Robotic Stripping System (LARPS) using a high pressure water process as an environmentally safe and effective paint removal system.

The robotic system is being developed independently of the high pressure water system. The robotic system will be designed to handle large military aircraft such as the Boeing C-135, B-52, and E-3 and the Rockwell B-1B. Hanger, aircraft preparation and system mapping may be different for each aircraft but the system will be essentially the same.

The procedure for qualifying a high pressure water blasting system has been broken down into three parts, I) Process Optimization, ii) Process Validation Testing, and iii) Additional Materials testing. As of 1992 the process optimization has been completed and the process validation testing has begun.

The process optimization study resulted in the following parameters for use in the high pressure water process:

- maximum operating pressure - 24,000 psi
- water flow rate - 20 l/min
- traversal speed - 25 mm/sec
- standoff distance - 37 mm
- stripping rate - 1.25 ft^2/min per nozzle

Using the above parameters residual stress measurements using the Almen Strip method gave Almen arc heights of less than 75 μm for 2024-T3 aluminum alloy. Surface roughness measurements under the same blasting conditions resulted in surface roughness increasing from 23, 36, 67, 126 μin through four blast cycles on Al 2024-T3 alclad. Further process validation studies are planned to include composite surfaces (glass fibre and graphite fibre), aluminum and fibre honeycomb structures and joints, lap joints and fasteners to investigate sealant integrity and water intrusion.

6. ICE PARTICLES

Ice blasting will be discussed in more detail in a subsequent lecture. Ice blasting was developed by RETECH (now Ice Blast International), under contract to Defence Research Establishment Pacific, as a dust free blasting technique for confined spaces such as ship bilges and machinery spaces. More recently it has been shown to have further application in paint removal from delicate substrates that can be damaged by conventional blasting techniques and as a cleaning technique for soiled or contaminated surfaces.

Ice particles offer several advantages as a blasting medium. They are not abrasive and fracture under a high load such as impact with a substrate, thus limiting the impact force and thereby preventing damage to delicate substrates. Ice is also a dust free media that melts to water. The spent medium, namely water, can be easily removed from the coating debris and can be disposed of leaving the debris to be handled as a known hazardous waste disposal problem.

The use of ice blasting is also being considered by the CF as a method for cleaning soiled aircraft coatings, removing decals from aircraft, removing paint from delicate surfaces such as Kevlar and graphite epoxy

composites, and as a possible method to clean aircraft components such as gas turbine blades.

Concerns about the environmental aspects of the disposal of the spent media from plastic media blasting or traditional grit blasting could lead to more serious consideration of ice blasting for the stripping and cleaning of entire aircraft or other equipment.

7. CARBON DIOXIDE (DRY ICE) PARTICLES

7.1 Dry Ice Particles

The major advantage of carbon dioxide (CO_2) pellets is that there is no media residue after blasting. One disadvantage is that it must be removed from enclosed spaces to ensure the safety of personnel and an adequate source of breathable air.

Two German companies have investigated dry ice pellets (Deutsche Airbus, Dornier and Messer Grieshiem Company). Dry ice blasting alone was not found to be particularly effective in removing well prepared paint systems with stripping rates of 1 m^2/hr. If used in combination with paint softeners, rates of up to 15 m^2/hr were observed, but this rate only occurred if the paint system was completely blistered by the softener.

Three US companies have been or are also developing dry ice blasting processes. Research and testing of dry ice blasting for aircraft is ongoing. A Boeing 707 at the Smithsonian Museum was stripped using dry ice blasting and the process has been evaluated for F-15, C-141 and C-130 aircraft.

Impact of CO_2 particles can do considerable damage. For example, in the German study, anodized and alclad layers show micro-ruptures and micro-fissures, micro-fissures were observed on composite surfaces along with upper-layer delaminations and in some cases the coating on the backside of the panel was removed during blasting. From this study it was concluded that CO_2 blasting needed more refinement and should only be used in combination with paint softeners.

There are several disadvantages with the dry ice blasting process including:

- the requirement to store compressed liquid CO_2 on site
- the use of very high air pressures (up to 250 psi) that require large compressors
- the process is noisy because of the compressors and cryogenic equipment used in the process

The cleaning rates of CO_2 alone are quite low and a process combining CO_2 and flash lamps shows more promise.

7.2 Xenon Flash/Dry Ice

The development of a combined xenon flash lamp/carbon dioxide pellet blasting by Warner Robbins Air Logistics Center (WR-ALC) and McDonnel Douglas Aircraft Company (McAIR) carries the trademark *FLASHJET™*.

A xenon flash lamp emits sufficient energy to ash the paint coating and the carbon dioxide blast is used to remove the residue.

The *FLASHJET™* process can selectively remove polyurethane coatings down to the epoxy primer leaving the primer intact. This process therefore does not damage the substrate or affect the following properties:

- mechanical properties of thin, structural aluminum
- mechanical properties of graphite epoxy
- adhesive bond strength
- repaint adhesion or corrosion resistance
- fatigue life of Al 2024-T3 or Al 7075-T6
- Almen test results indicate deflection of less than 0.0005 inches.

The process is capable of stripping at rates of up to 2.8 ft^2/min down to bare substrate and 4 ft /min to remove only the topcoat (polyurethane/epoxy coating system).

The *FLASHJET™* process is now a commercially

available production process for coating removal from aircraft components.

8. BICARBONATE OF SODA

Crystalline sodium bicarbonate is an odourless, non-flammable, water soluble abrasive material. Sodium bicarbonate is used in food and pharmaceutical applications. The blast particles are crystalline with sharp and jagged edges but produce a dusty environment unless water (2 L/min) is injected into the blast stream. The material is soluble in water and this can be used as a method of separating the blast media from paint particles.

Sodium bicarbonate has been under evaluation for paint removal from aircraft for a number of years and has been shown to be effective.

Concerns about the possible corrosive effects of sodium bicarbonate on aluminum structures have been addressed by the manufacturer. An inhibitor has been added to reduce the corrosive effect and it has been demonstrated the sodium bicarbonate is no more corrosive than previously used chemical strippers.

Sodium bicarbonate has been used in the following applications:

- remove grease, contamination and coatings from a variety of structures
- remove baked-on-food and other residue from baking equipment
- remove coatings from wood and fibreglass marine structures
- cleaning of circuit boards, and
- cleaning automotive parts

9. PAINT SOFTENERS

As an alternative to blasting methods, paint softeners have been developed that do not use chlorinated hydrocarbon solvents. The softeners are generally alcohol (alcalic) or acid based and are considered less polluting than paint strippers based on chlorinated solvents; they are also biodegradable.

Experience has shown that different polyurethane coating formulations react differently with softeners. Some blister at room temperature after 30 minutes exposure while others require higher temperatures (up to 40°C) and longer exposure times (up to 24 h).

The major concern with all paint softeners is the possibility of a reaction between the softener and the base material. Exposure of aluminum alloys to acid based softeners for eight hours at 40°C resulted in weight loss in the range of 0.1-0.3%. SEM observation noted the loss of the oxide layer and the initiation of corrosion on the surface. No weight loss or changes in the surface was noted with alcohol based softeners (benzylalcohol containing). No reduction in fatigue behaviour or strength was observed with either type of softener.

No change in flexural strength or interlaminar shear strength were observed using either type of softener on duroplast composites. Benzylalcohol based softeners reduced the interlaminar shear strength of a thermoplast composite to an unacceptable level.

10. STRIPPABLE COATINGS

By design and formulation, a coating can be made strippable chemically in a short period of time using environmentally friendly paint strippers (methylene chloride-free and phenol-free).

Selectively strippable coatings are based on one of two principles:

- intermediate coating that is easily removed, or
- a barrier coat not removed in the stripping process

The disadvantage of the barrier coating method is that coating thickness builds up in multiple stripping and repair procedures. It has also proven difficult to obtain a good balance between adhesion and strippability in the barrier coating and the barrier coating makes it more difficult to detect cracks in the anti-corrosive primer.

ICI has developed an intermediate coat system consisting of an epoxy primer, intermediate coat II and a modified polyurethane topcoat. It has been

independently shown that this coating system can be removed in under two hours using non-chlorinated chemical strippers (pH neutral).

Experience with this system on the Airbus A320 showed that after three years, the polyurethane topcoat and intermediate coat could be removed with a non-phenolic stripper . Topcoat lifting occurred after 5 minutes and complete removal down to the epoxy primer occurred within 30 minutes, leaving an intact epoxy primer.

Paint Removal Principles

Mr. Olivier Malavallon
Aérospatiale
Direction des Etudes
A/DET/CG-MP
Toulouse Est. 316 route de Bayonne
31060 Toulouse Cedex 03
FRANCE

On the question of paint removal, the number of listed processes - in use, under development and under study - appears very high and very varied.

In order to better understand this situation, it is useful to group these processes into families.

1 CLASSIFICATION

From among the various types of listed classifications, the classification chosen is the one taking the physical phenomena involved in the material removal process into account.

The physical phenomena allowing material removal to achieve paint stripping are as follows:
- chemical,
- mechanical,
- thermal.

These principles can be used either one by one in the elaboration of a process which is then considered as «simplex» or they can be combined to obtain better results. Today, the main combinations are of the «duplex» type, such as:
- chemical + mechanical,
- thermal + mechanical.

2 DESCRIPTION

It is possible to define an operating method for all paint stripping processes independent of the process studied:

a) cleaning, degreasing, drying and masking,

b) application of the stripping process to the surface,

c) paint stripping,

d) removal of paint residues (by scrapping, rubbing down, water jet, etc.),

e) if necessary, complete or local reapplication (repeat of b) + c) + d)),

f) demasking and final cleaning,

g) recovery and processing of waste.

According to type of physical phenomenon and process used, note that :

- steps a) and f) are more or less reinforced and increased,
- steps b) and c) can be carried out almost simultaneously or completely dissociated,
- phase d) and e) depend mainly on the efficiency of the process.

Nevertheless, for each of the three basic physical phenomena, it is possible to identify the main mechanisms brought into play in material removal leading to paint stripping.

3 STRIPPING PROCESSES

3.1 Chemical stripping

In the case of chemical stripping, the operating method used is as described in § 2 and requires the carrying out of all identified steps.

Although the operating methods and the physico-chemical mechanisms are almost the same, the use and efficiency of these products vary. They depend mainly on the type of chemical strippers used. These can be classed by their known compositions structured around one or more active chemical constituents.

These chemical constituents are as follows:

- methylene chloride,
- phenolic compounds,
- activated acids or activated bases free from phenols, chromates or methylene chloride.

Originally, the physico-chemical mechanisms used by most strippers were based on the action of methylene chloride. This molecule has high polarity and a high solvent power. When this molecule is used, the following reactions are generated:

- migration of the solvent molecules ($CH_2\ Cl_2$) through the layers of paint which are similar to a macromolecule network,
- accumulation of the migrating particles as soon as they encounter a modification in the macromolecular network,
- solvation leading to a swelling of the paint,
- loss of cohesion between the various layers of paint by electrostatic reaction of the methylene chloride molecule with the small-size molecules.

For products in which phenolic compounds replace methylene chloride, the mechanisms brought into play are the same.

Lastly, a new generation of chemical strippers, free from chromates, methylene chloride and phenolic compounds, has been engineered from activated acids or activated bases. The physico-chemical reactions generated are similar to those generated by methylene chloride. However, the molecules used are less active and their solvent power is lower. To improve the chemical kinetics, «active» elements are introduced into the composition of these products.

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

3.2 Mechanical stripping

This family of stripping processes includes technologies using mechanical phenomena based on erosion. Erosion can be generated by friction of tools such as sanders or brushes. Erosion can also be achieved by blasting small-size particles onto the surfaces to be treated.

For mechanical stripping, if operating method is as described in § 2, steps a), e), f) and g) can be significantly reduced and steps b) and c) carried out simultaneously.

3.2.1 Friction

These processes are mainly manual. The operator exerts pressure on the surface to be treated either directly or using mechanical assistance. Movement of the tool used is associated with this pressure. The aim of these movements is to homogenize the surface under treatment, avoid local heating and control work progress.

3.2.2 By blasting particles

Initially manual, these processes have undergone sustained industrial research and are now either semi-automated or completely automated.

This type of technology consists in blasting particles onto the surface to be stripped by means of a carrying fluid. The carrying fluids generally used are water and air.

These particles, also called media, can be of different physico-chemical types:

- mineral («sand», corundum),
- organic (wheat starch media, nut shells, etc.),
- synthetic (plastic media),
- crystalline (H2O ice, dry ice),
- liquid (water, etc.).

Also, these particles can be characterized by a grain size and a density.

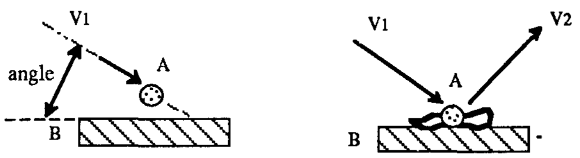
Generally, the media are introduced into the carrier fluid at the level of a subassembly called «nozzle» then accelerated in the nozzle.

When the media hit the surface, there is a sudden transformation in its kinetic energy:

- in the form of work dissipated by the erosion phenomenon,
- in the form of a new rebound kinetic energy.

In addition, for certain media, this mechanical shock can cause cracking of the superficial paint layers. This sustained cracking allows the infiltration of the media and causes lack of cohesion between paint coats.

Schematic diagram:



a = stripping angle
V1 = blasting speed
V2 = rebound speed
(where V1 > V2)
A = particle
B = substrate

The main parameters influencing these types of processes are:

- type of media,
- media flow rate,
- carrier fluid pressure (inducing speed),
- type of nozzle,
- angle between nozzle centerline and substrate.

3.3 Thermal stripping

These fairly recent processes are based on sophisticated technologies making extensive use of electronics and automation.

At present, the principles of the processes developed are mainly based on supplying of thermal energy. The energy transmitted to the paint substrate under certain conditions allows the internal molecular bonds of the paints to be broken.
Energy is supplied by radiation. According to type of radiation used, different paint degradation modes are observed.

In the case of thermal stripping, if the operating method is as described in § 2, steps a), e), f) and g) can be significantly reduced and steps b) and c) carried out simultaneously.

3.1 Thermal mode

This stripping mode is suitable for certain wavelengths. The radiation is emitted in the direction of the substrate to be treated. It accumulates locally on the surface in the form of heat.
This accumulation of energy then allows the molecular bonds to be thermally broken.

The accumulation required for stripping depends mainly on the energy of the photons used, the paint absorption coefficient and the frequency of the energy pulses.

3.3.2 Photoablation

In this case, the stripping mode used is photochemical. The radiation emitted generates protons whose energy is greater than that of the molecular bonds. In theory, each proton emitted can directly break one of these bonds.

4 - STRIPPING LEVELS

4.1 Reminders

On aircraft, external paint schemes are applied to almost all external surfaces, independent of the substrates, whether these are metallic or composite.

However, these substrates are never bare, but almost always covered by appropriate surface treatments mainly to protect them against corrosion phenomena or electrostatic phenomena. In reality, the paint schemes are applied to these protected substrates.

These external paint schemes in general consist of a stack of different layers. Each of these layers is defined and used for a precise purpose and meet specific technical requirements. Also, on account of this stack, each paint coat interfaces with at least another coat in the paint system considered.

An external paint scheme generally consists of the following paint coats:

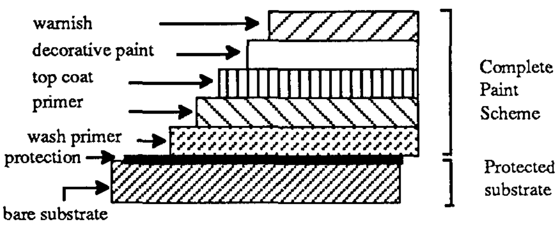
- wash primer,
- primer,
- top coat,

to which the following can be added for certain applications:

- decorative paint,
- varnish.

The situation can be summarized as shown on the diagram below:

General paint diagram



4.2 Selective stripping

4.2.1 Definition

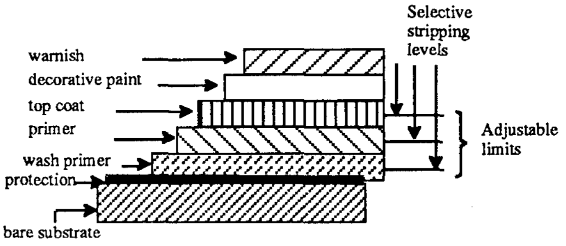
When a process is capable of achieving continuous and uniform stripping removing a certain paint thickness - without however removing the entire paint system - stripping is said to be selective.

In practice, for an external paint scheme, this consists in being able to remove certain layers located on the surface (such as varnish, decorative paint, top coat) without removing or damaging the underlying coats (such as wash primer or primer).

4.2.2 Benefits

This type of stripping, when it can be performed, can be used to brighten up or change the livery of an aircraft. Potentially, it allows cycles to be reduced, avoids increases in weight whilst limiting structural inspections before repainting.

Diagram: selective stripping



4.3 Complete stripping

4.3.1 Definition

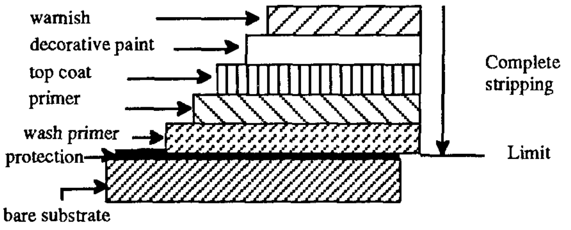
If a stripping process is capable of totally removing the external paint scheme without damaging or modifying the substrate and its protection, stripping is called complete.

Note: If the stripping reaches the bare substrate, that is removing all protections covering it, the operation is called conversion.

4.3.2 Benefits

This type of stripping, when it can be performed, can be used to make repairs to or inspections of the aircraft structure. It also allows the paint scheme to be changed without incurring weight penalties.

Complete stripping diagram



4.4 Comments

The capacity of a process to achieve selective stripping or complete stripping («tolerance» notion) depends on several criteria:

- external paint scheme considered,
- stripping principle or principles retained and used by the process,
- type of substrate to which the paint is applied,
- technologies used and control of stripping parameters.

Lastly, it appears that certain processes can intrinsically only perform selective stripping or complete stripping operations.

BACKGROUND TO PLASTIC MEDIA BLASTING

Dr. Terry Foster
Esquimalt Defence Research Detachment
FMO Victoria
Victoria, B.C., Canada V0S 1B0

1. INTRODUCTION

Chemical strippers based on active phenolic components in a chlorinated solvent have been the traditional method for removing of paints and coatings from aircraft. With the recent recognition of the environmental and health concerns of chlorinated solvents and the problem disposing of phenols there have been some major developments in paint removal technology. One of the first techniques developed to replace chemical strippers and now one of the most widely used techniques for paint removal from aircraft was plastic media blasting (PMB).

The PMB technique is similar to traditional grit blasting (slag, sand alumina or Carborundum) techniques used on steel and other metals based on grits) but using polymer based media that are softer and less aggressive. Plastic media are ranked by hardness and density as well as chemical composition. Plastic media are also available in a variety of mesh sizes ranging from 20 to 60 mesh or a selected distribution of sizes. A list of the various media types and their physical properties are shown in Table 1. The classification is based on the US MIL SPEC Mil-P-85891.

While the Type II, urea formaldehyde, was the first media in general use in many applications and facilities, it has recently been replaced by the Type V, acrylic, media. This is the media currently specified by the Canadian Department of National Defence (DND) for stripping Canadian Forces (CF) aircraft and is specified at many US Air Force (USAF) facilities. The other media are used for specific applications but do not find widespread application in aircraft stripping.

There are still restrictions on the use of PMB, especially on commercial aircraft. For example, the IATA Taskforce on Paintstripping did not recommend PMB due to the possibility of damage to the aluminum alloy (2024-T3) used on most commercial aircraft.

There are also limitations on the use of plastic media on aircraft written into many specifications. The following are situations and conditions that may restrict or preclude the use of plastic media:

- nature of the substrate - thin section aluminum or composites such as kevlar
- type of coating, especially hard or resilient types that are difficult to remove
- the need to mask part of the aircraft to prevent ingress of media into the structure
- the dust must be contained during blasting and must be controlled to prevent health problems for workers
- the media must be recycled to be cost effective
- the media and paint are generally considered a hazardous waste and must be disposed in accordance with local regulations.

2. PLASTIC MEDIA TYPES AND CHARACTERISTICS

The following descriptions of the various plastic media are based on the US Military Specification Mil-P-85891. The descriptions are taken from the technical data sheets produced by the manufacturers, from the Composite Materials Co. Inc, Technical Data Sheets and from the AFSC Design Handbook "Paint Stripping Technologies - Plastic Media Blasting (PMB) and Other Abrasive Grits".

2.1 Type I, Polyester

Polyester is a thermoset resin usually produced in cast sheets and unlike the other phenolic resins is produced in the unfilled form. Because of its low density and sharpness it removes coatings through a chipping rather

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

than abrasive process. The advantage of this is

TABLE 1 -- BLAST MEDIA PROPERTIES

MEDIA	CHEMICAL COMPOSITION	HARDNESS		DENSITY
		MOH	Barcol	(g/cm^3)
Type I	Polyester	3.0	34 - 42	1.04 - 1.46
Type II	Urea Formaldehyde	3.5	54 - 62	1.47 - 1.54
Type III	Melamine Formaldehyde	4.0	64 - 72	1.47 - 1.52
Type IV	Phenol Formaldehyde	3.5	54 - 62	1.38 - 1.42
Type V	Acrylic	3.5	46 - 54	1.17 - 1.20
Type VI	Polyallydiglycol Carbonate	3.0	30 - 40	1.3 - 1.4

that very little residual stress is produced in Al 2024-T3 Almen tests but the coating removal process is considerably slower than for Types II and III.

Type I media has not found general application in the aircraft industry but is used extensively in the electronics industry and to remove coatings from fibreglass and composite materials.

2.2 Type II, Urea Formaldehyde

Urea formaldehyde is a thermoset resin produced by the controlled reaction of formaldehyde with amino (NH_2) resins. The media is generally made from urea molding compounds to which alpha cellulose fibres have been added to increase strength rather than from virgin material produced specifically for plastic media. This media was one of the original developed in the early 1980s for paint stripping and was studied extensively by both the US and German Air forces. More recently this media has been superseded in many applications and specifications by the Type V, acrylic media.

This media is generally used on Al 7075-T6 under the following blasting conditions:

- blast pressure 30 - 40 psi
- standoff distance 18 - 24 inches
- blast angle 45 - 90°

Almen arc heights of 0.002 - 0.010 inches have been observed for Type II media on Al 2024-T3. Type II media can have a pronounced peening effect of some aluminum surfaces such as Al 6061 and is generally not used on thin aluminum or composite components.

2.3 Type III, Melamine Formaldehyde

Melamine formaldehyde resin is produced in a similar manner to the urea formaldehyde resin except there is increased chemical cross-linking that produces a harder resin. The material used in paint stripping is generally recycled media containing alpha cellulose and not from sheet produced specifically for blasting media. As this media is harder than Type II, it has not found much general purpose use in the aircraft industry. Almen arc heights as high as 0.014 inches have been found on Al 2024-T3.

2.4 Type IV, Phenol Formaldehyde

Thermoset phenolic resins are produced by the polymerization of formaldehyde and phenol. This media is generally cellulose filled similar to Types II and III. Very little data is available on this type of media due to the extensive early use of Types II and III.

2.5 Type V, Acrylic

Acrylic polymers are formed by the free radical initiated polymerization of methyl methyl

methacrylate (MMA). The acrylic media used in PMB is generally produced by cryogenic grinding. This reduces heat buildup during the grinding process and results in a sharper more aggressive media.

Type V media is becoming the workhorse of PMB with physical properties between Types I and II. The acrylic media has been used successfully on thin section aluminum (less than 0.016 inches) and on graphite epoxy surfaces. As the acrylic media is an unfilled polymer there is very little dust produced during blasting. Almen arc heights in normal blasting conditions are generally less than 0.005 inches on Al 2024-T3.

2.6 Type VI, Polyallydiglycol Carbonate

Allyldiglycol carbonate is a cross-linked (allyl with unsaturated polyester) thermoset polymer. This material is used for its optical transparency and light weight in lenses for eyewear. The material used for plastic media is unfilled.

When ground this material gives sharper edges than Type V and in some cases can be effective at lower operating pressures than Type V media. The allyl media lies between Type II and Type V in density but is of similar hardness to Type I.

This media has applications similar to Types I and V. For example it has been used to strip composite and fibreglass surfaces as well as magnesium and aluminum surfaces. This media has not been studied to the same extent as the other types and thus its effects on various materials has not been completely characterized.

Dry Media Blasting with Wheat Starch

Dr. Terry Foster
Esquimalt Defence Research Detachment
FMO Victoria
Victoria, B.C., V0S 1B0
CANADA

1 - ORIGINS

1.1 Development

First, we must recall that a particle blasting stripping system schematically consists of several entities. These are as follows:

- a media conditioning and processing assembly,
- a media acceleration, blasting and recovery assembly,
- a monitoring/control/travel assembly,
- a carrier assembly allowing installation,
- and lastly, the media used.

In the case studied, the origins are various.
Thus, by purchasing and conducting studies on patents filed by the Canadian company COMPUSTRIP, the French company CENTRE Industrie and its Canadian subsidiary INTECH Aeronautic Int. developed the TECHNOSTRIP scheme at the end of 1992. Their work mainly concerned the improvement of the carrier assembly, the media acceleration/blasting/recovery assembly and the monitoring/control/travel assembly.

In addition to this activity, wheat starch media was developed by the Canadian company ADM-OGILVIE which tested and industrialized it for this type of application. Finally, it is on the basis of standard plastic media conditioning and processing equipment that a specific assembly was developped by CENTRE Industrie.

Furthermore, CENTRE Industrie has led a specific research and development program in order to optimize the efficiency of nozzles conventionally used for stripping. By correlation between two-phase flow simulations on computer and stripping tests using nozzles with new forms, CENTRE Industrie elaborated and filed an international patent for a nozzle called «flat nozzle» (end of 1993).

1.2 Partnership and improvements

Already during the development of the COMPUTERSTRIP 2000 demonstrator, AEROSPATIALE and AIR FRANCE cooperated with the Canadian company. This gave rise to technical demonstrations in Toulouse and Paris-Orly.

AEROSPATIALE and AIR FRANCE cooperated from late 1992 with CENTRE Industrie. This technical cooperation was achieved mainly in the form of applied research and development contracts and also technical exchanges and information relevant to the aeronautic field.

The main concrete results from this cooperation are described in § 6 and 8.

2 - FACILITIES AND INSTALLATIONS

The brand name TECHNOSTRIP registered by CENTRE Industrie in 1993 covers several types of installations and facilities. These were developed mainly to meet the requirements of customers in the aeronautic field.

This range of products includes:

- complete self-supporting and semi-automated system (including all subassemblies) for aircraft stripping,
- large-size blasting booth for semi-automatic stripping,
- manual blasting booth,
- sealed and portable manual stripping head.

2.1 TECHNOSTRIP'S complete self-supporting system

This system was developed to strip external surfaces of aircraft using a fairly basic and available infrastructure such as a maintenance hangar. By design, the system integrated, from the outset, all subassemblies allowing autonomous operation. Only the electricity and compressed air supplies are to be provided.

In this version (see diagram 1), the system is self-propelled and can be dismantled for transport to a geographically remote maintenance site. It consists of:

- a modified self-propelled carrier (GROVE), equipped with a telescopic arm the end of which accommodates a horizontal beam along which the articulated arm (see diagram 2), supporting the stripping head, moves.
  To this, we must add a control station equipped with all positioning, control, adjustment and safety systems.

- a movable trailer including all the media conditioning and processing subassemblies and the waste recovery system (see diagram 3). The media are fed to the stripping head through flexible hoses and waste recovered after stripping is returned via flexible hoses for processing on the trailer.

The stripping head has been constantly studied and improved.
This subassembly contains in a compact volume (see diagram 4) :

- the blasting nozzles for the media conveyed and projected by compressed air,
- the stripping waste suction device,
- the computer-assisted display system,
- the sealing devices preventing all leaks (of air and waste) when movements are made during stripping,
- the head/surface bearing and positioning compensation systems,

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

- and the safety systems.

For the starch media treatment, ADM Ogilvie and then CENTRE Industrie demonstrated that it can be used several times and that its optimum operating range is between 5 and 15 cycles (see diagram 5).
This characteristic allows an optimized volume of media to be carried in the tank installed on the trailer allowing sufficient autonomy while minimizing the weight and dimensions of the trailer's subassemblies.

The positioning and travel system of this motorized installation allows it to be positioned in space with regard to the aircraft and then with regard to the surface to be stripped in a reliable and operational manner (see § 4).

2.2 - Large-size blasting booth for semi-automatic stripping

By design this cabin of modular length uses most of the subassemblies developed for the self-supporting system. In a closed and ventilated chamber, a flat nozzle is used in open jet mode. Travel is acheived by means of a suspended arm adjustable vertically on OZ axis which itself is carried on a gantry on which travel is controlled along transverse axis OY. The gantry itself moves along booth longitudinal axis OX. Nozzle travel can be programmed and supervised from outside the booth or a computer-assisted display installation can be used to optimize stripping performance.

The starch media and the stripping waste are collected via the floor specially designed for this purpose. They are then transferred to the conditioning and processing installations located outside of the booth (see diagram 6).

2.3 - Manual blasting booth

This is a conventional manual blasting booth (volume of around 1 m^3) equipped with a pair of flexible gloves. The nozzle used is a flat nozzle supplied with media and compressed air via a flexible hose. This hose is connected to the starch media conditioning and processing installation and to a media metering, acceleration and recovery assembly. Blasting is in open jet mode within the volume of the booth.

The blasted media and stripped paint residues are collected via the bottom of the working surface (see diagram No.7).

2.4 - Manual stripping head

The manual stripping head is designed to complement the semi-automated self-supporting system. It is supplied via a connection provided for this purpose on the trailer. This head consists of a flat nozzle supplied with compressed air and starch media via a flexible tube.

The paint waste and starch media are recovered and fed to the trailer via a hose for conditioning and processing. A window on the upper part of the stripping head allows the operator to check stripping obtained (see diagram 8). The operator triggers blasting and moves the head by pressing it onto the surface to be stripped.

Depending on travel rate controlled by the operator, this tool can perform complete or selective stripping.

3 - USE

On account of its innovative aspect, we will mainly deal with the complete self-supporting system TECHNOSTRIP. Utilization methods for the other systems are, by design, either based on the self-supporting system or conventional.

The processing to be applied to the aircraft or to all elements removed from an aircraft is as follows:

- step 1 : cleaning and visual inspection,
- step 2 : degreasing,
- step 3 : masking (and, if necessary, zoning of substrates),
- step 4 : positioning,
- step 5 : semi-automated stripping,
- step 5a : manual stripping and finishing,
- step 6 : cleaning,
- step 7 : demasking and visual inspection.

3.1 - Cleaning and visual inspection

The aim of this step is to inspect the external surfaces of the aircraft before performing the stripping operations. All surface defects or anomalies must be identified, marked on the drawing and, if necessary, treated or protected for repair at a later stage.

3.2 - Degreasing

After cleaning of the external surfaces of the aircraft, contamination may remain due to products such as greases, oils, fuel, hydraulic fluid, silicones, etc.. If residual products of these types remain on the surface of the aircraft they may hinder the repainting of the aircraft after stripping.

They must therefore be eliminated, on the one hand, to prevent them from being embedded into the surface and, on the other hand, so that they will not contaminate the recycled media.

3.3 - Masking

By design, the stripping head is almost completely tight. Dust, paint residues and media are confined underneath this head. However, all areas which may be damaged, either intrinsically or in their function, by the stripping process must be masked.

Thus, certain parts such as windows and window frames may require protection. Also, cavities, seals, drain holes, air inlets, etc. must be masked to avoid retention or accumulation of media detrimental to their correct operation.

Note that, if the stripping head movements are adequately programmed, all these precautions can be significantly reduced.

Note :
Surfaces with metallic substrates (and associated thicknesses) and surfaces with composite substrates (together with their type of protection and structure) must be checked and, if necessary, identified on the aircraft by zoning.

This step is required as the qualified stripping conditions may be limited to certain thicknesses or require additional maintenance operations after stripping.

3.4 - Positioning

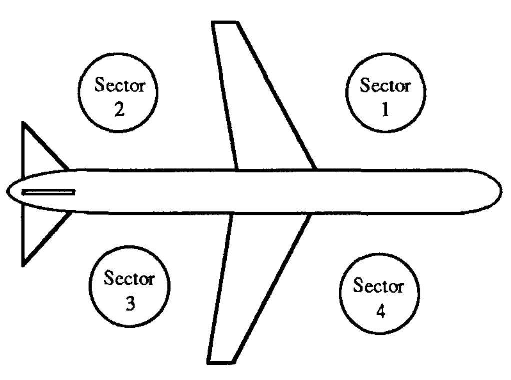
To use the processing power and accuracy that automated and/or computerized systems offer to the full, they must first of all be correctly positioned with regards to the surfaces to be stripped. However, as aircraft never have the same weight or same attitude, the self-supporting system must be initialized with regard to the aircraft reference system before all stripping operations are started.

CENTRE Industrie has developed a triangulation method which, by data processing, allows the system to be positioned or allows it to know its position with regard to the aircraft. This method is covered a patent.

The position is acquired thanks to a dimensional data bank available in the TECHNOSTRIP system computer relevant to the aircraft configuration. Thanks to the various sensors installed on the carrier, the beam and the arm, the position of the stripping head can be permanently known and controlled.

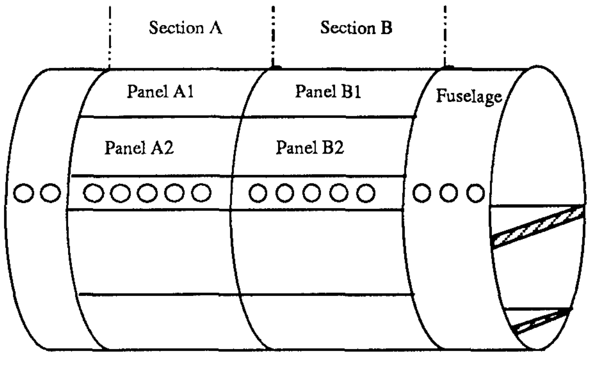
To perform stripping, the aircraft surface access regions are split into 4 sectors.

Diagram :



Once positioned in its «sector», the TECHNOSTRIP system maps the surfaces to be stripped into «sections». To go from one section to another, the position of the telescopic arm of the carrier must be changed and the beam moved with regard to the surface so that it remains flat against and parallel to the next surface to be stripped. The «panels» are then positioned within each of these «sections». A «panel» corresponds to the maximum surface area that can be stripped by the stripping head driven by the arm without having to move the beam.

Diagram :



Once the area to be stripped has been selected, the stripping head positions itself over the panel by appropriate movements. Then, by a slow approach movement, it comes into contact with the surface, positions itself by means of its actuators so that it continuously and tightly bears on the surface.

3.5 - Semi-automated stripping

When the stripping head is tightly in contact with the surface to be stripped, the compressed air and media are blasted through the nozzles at stripping head level. The metallic masks installed in front of the nozzles protecting the surface retract and the head moves.

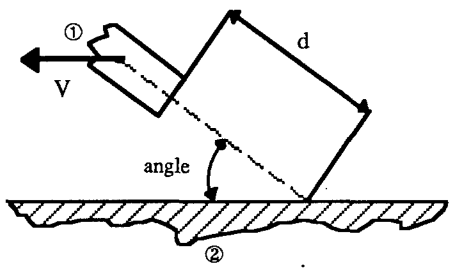
The head moves longitudinally and parallel to aircraft surface. When the length of the «panel» has been covered, the arm moves the head laterally through a distance equal to stripping trace.

During this operation, the metallic masks installed in front of the nozzles protect the surface.

The stripping parameters are defined to strip the surface without damaging it. The parameters, distance and angle are fixed by the shape of the stripping head. In addition, media grain size is kept constant by a filtering and stirring system.

The air pressure and media flow rate parameters can be adjusted if applicable without, however, exceeding the maximum allowed reference value. Only travel speed is really variable.

Diagram :



Legend :

d	:	nozzle/substrate distance
a	:	nozzle centerline/substrate plane angle
V	:	nozzle/substrate travel speed
(1)	:	nozzle
(2)	:	substrate

Travel speed is adjusted by a computer-assisted display system which continuously allows the readjustment of the position of the stripping front.

The stripping parameters, optimized for the flat nozzle, allow a uniform stripping trace to be obtained with an almost straight front with very clearly-marked lateral edges.

However, on account of its dimensions and certain obstacles or access difficulties, only 80% of the external surfaces can be stripped in semi-automated mode.

3.6 - Manual stripping and finishing

Whilst a semi-automated system is working in a sector around the aircraft, stripping operations or, if applicable, finishing re-work operations can be performed manually. To achieve this, the operator equipped with the manual stripping head, can gain access and strip the designated surfaces from an aerial platform or a working platform.

This head is also equipped with a flat nozzle. However, its parameters are slightly reduced to avoid all damage to the substrate.
The operator places the head on and moves it over the surface to be stripped. He checks the result obtained visually through a window installed on the top of the stripping head.
By its size, this type of nozzle allows almost all the surfaces of the aircraft not accessible by a semi-automated system (15%) to be treated.

3.7 - Cleaning

After the painted surfaces have been stripped, the light film of dust covering the upper surfaces of the aircraft must be removed. This can be achieved by cleaning with equipment of the water jet type.

3.8 - Demasking and inspection

The last step in the stripping operation consists in demasking the previously protected areas. A visual inspection can be carried out to check that these masked areas have not been damaged or soiled by the stripping operation.

3.9 - Stripping level

By the optimization work carried out on the stripping parameters for the various painted substrates, selective stripping and complete stripping can be performed in a reliable and reproducible manner on both metallic and composite substrates. Optimum working conditions have been identified for metal substrates alone (complete and selective stripping) and others for composite material substrates (complete and selective stripping) which can also be used on metallic substrates. For metallic substrates, the complete stripping conditions are quite different from the selective stripping conditions; however, for composite materials, they are relatively similar.

4 - USE OF AUTOMATED FACILITIES

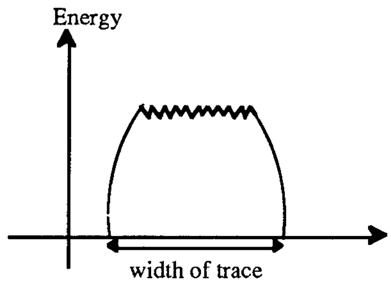
In order to obtain optimized results and best possible performance, automation and data processing were implemented at the design stage of the TECHNOSTRIP semi-automated system. The movements, positioning, stripping and check of the system's parameters are therefore automated and computerized and supervised by the technician using the system from his booth. Only the operations which allow the operator to be relieved of long and tricky tasks and that the machine can perform more rapidly and more reliably have been computerized. The other operations use conventional methods (mainly mechanical and manual).
The automation of the stripping operation and its monitoring by computer-assisted display allows stripping with stable and optimized operation which cannot be achieved by a conventional manual process without the risk of damaging the stripped structure.

5 - RELIABILITY

When repetitive operations must be performed on the structure of an aircraft worth several tens of millions of US dollars, preventive measures must be taken beforehand.

First of all, a semi-automated concept was favored during the definition stage (see § 4). Then, reliability and operating safety were implemented when elaborating and chosing the solutions.

The flat nozzle offers, by design, uniform energy distribution over the complete surface of the trace and presents no maxima.



Also, the design of the stripping head fixes the angular and distance parameters guaranteeing high precision. As for media flow rate and compressed air pressure, they are fixed by the operator and cannot exceed allowable limits.

The travel speed is adjusted by a computer-assisted display system which continuously allows the stripping front position, visualized by a camera, to be readjusted with regard to the theoretical stripping front position materialized by a line on camera's sight. Thus, if the real stripping front is a head of the theoretical front, travel speed is increased. On the other hand, if the real stripping front is behind the theoretical front, the travel speed is reduced.

Also, a device installed in the stripping head, and which can be positioned between the nozzle and the surface, can be used to prevent the blasted media from reaching the surface. This device is used:

- to set up the pass (lateral movement, see § 3.5),

- when travel speed is too slow (safety),

- to pass over a surface not to be treated,

- when head stops on detecting of an obstacle (safety).

Lastly, an anti-collision system has been specially designed to detect any obstacles at level of the stripping head and its supporting arm. This system also calculates the position of all elements which move with regard to the aircraft structure.

To finish, optimized operating points, defined by precise stripping parameters, have been tested and validated with success under conditions considered as unfavorable for the aircraft structure.

6 - EFFECTS ON MATERIALS

6.1 - Selective stripping

Finally, selective stripping can be performed on metallic substrates and on composite material substrates.

- *On metallic substrates*, the paint system is stripped down to the primer with good productivity. Surface finish Ra obtained is around 3 microns.
  Deflection on aluminium type-C Almen test specimens is very low. Adherence of residual paint on the substrate is perfect.
  Overlapping of two traces, either laterally or crossed, does not damage the selectively stripped surface on metallic substrates.

- *On composite material substrates*, selective stripping can be achieved down to the primer on carbon, glass/ carbon hybrids, monolith or sandwich structure Kevlar using epoxy resins. Selective stripping can also be achieved on substrates protected électrostatically by bronze mesh.

- Surface finish Ra obtained is around 8 microns. No damage to the substrates has been observed either visually or by non-destructive testing. Adherence of residual paint on the substrate is perfect.

6.2 - Complete stripping

- *On metallic substrates*, in particular aluminium alloys, complete stripping can be achieved without damaging their corrosion protections. Surface finish Ra obtained is 3 microns. Deflection curve on aluminium alloy type-C Almen test specimens fulfills the IATA requirements. Fatigue tests show no reduction in fatigue for aluminium alloys (unclad test specimens).

- *On carbon/epoxy* and glass-carbon/epoxy hybrid composite materials, complete stripping can be achieved but requires additional control and precautions. Surface finish obtained is around 7 microns.

7 - EFFECTS ON ENVIRONMENT

In operation, the TECHNOSTRIP installation, consisting of the stripping plate and the starch media conditioning and processing assembly, does not exceed a noise level of 75 dBa.

Also, in order to avoid all risks of possible explosions due to the accumulation of very fine particles in suspension, the grain size used and the filtering systems have been defined and tested to never reach a potentially critical zone.

In addition, the sealing of the stripping head has been carefully studied to reduce risks of compressed air, media and stripping residue leaks to a minimum.

Lastly, dry stripping by blasting wheat starch media offers the same advantages for the environment as plastic media blasting (P.M.B.) with, in addition, the fact that it uses organic biodegradable media.
Stripping waste can be processed by a procedure called bioremediation (see wheat starch bioremediation presentation) allowing 95% of the residues to be eliminated. The only substances which remain are the inorganic elements and the heavy metals contained in the paints and protections on the surface of aircraft.

8 - UTILIZATION EXAMPLES

8.1 - Metallic substrates

- AIRBUS A300/A310 fuselage

  . semi-automated TECHNOSTRIP system

  . stripping of clad and unclad aluminium alloy substrates on fuselage

  . MSN 079 and MSN 129 belonging to AIR FRANCE

  . process authorized by NTO by AIRBUS following a special test program.

- CFM 56 engine fan

  . in manual booth

  . O.G.U. substrate

  . stripping to remove initial paint

- Hydraulic casing for helicopter

  . in manual booth

  . magnesium substrate

  . removal of sealant joints.

8.2 - Composite material substrates

- Elevator repair

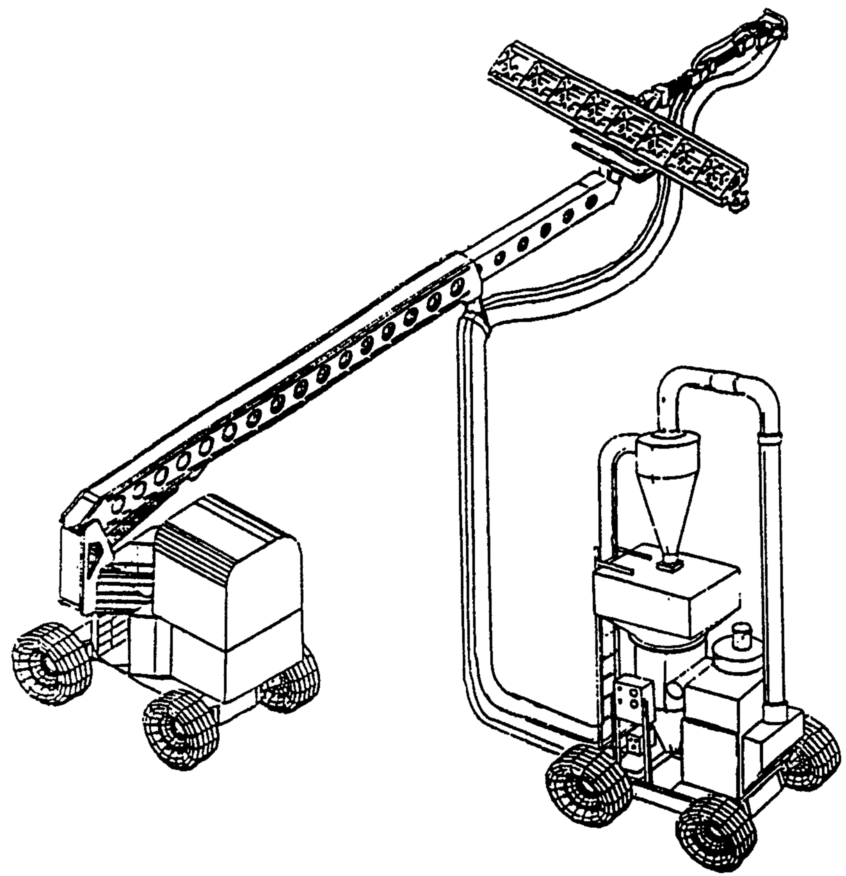
  . in 10 m x 3 m booth, installed and used at AEROSPATIALE, Nantes facilities,

  . stripping of external protection applied to carbon fiber epoxy sandwich substrate,

  . process qualified by AIRBUS Industrie.

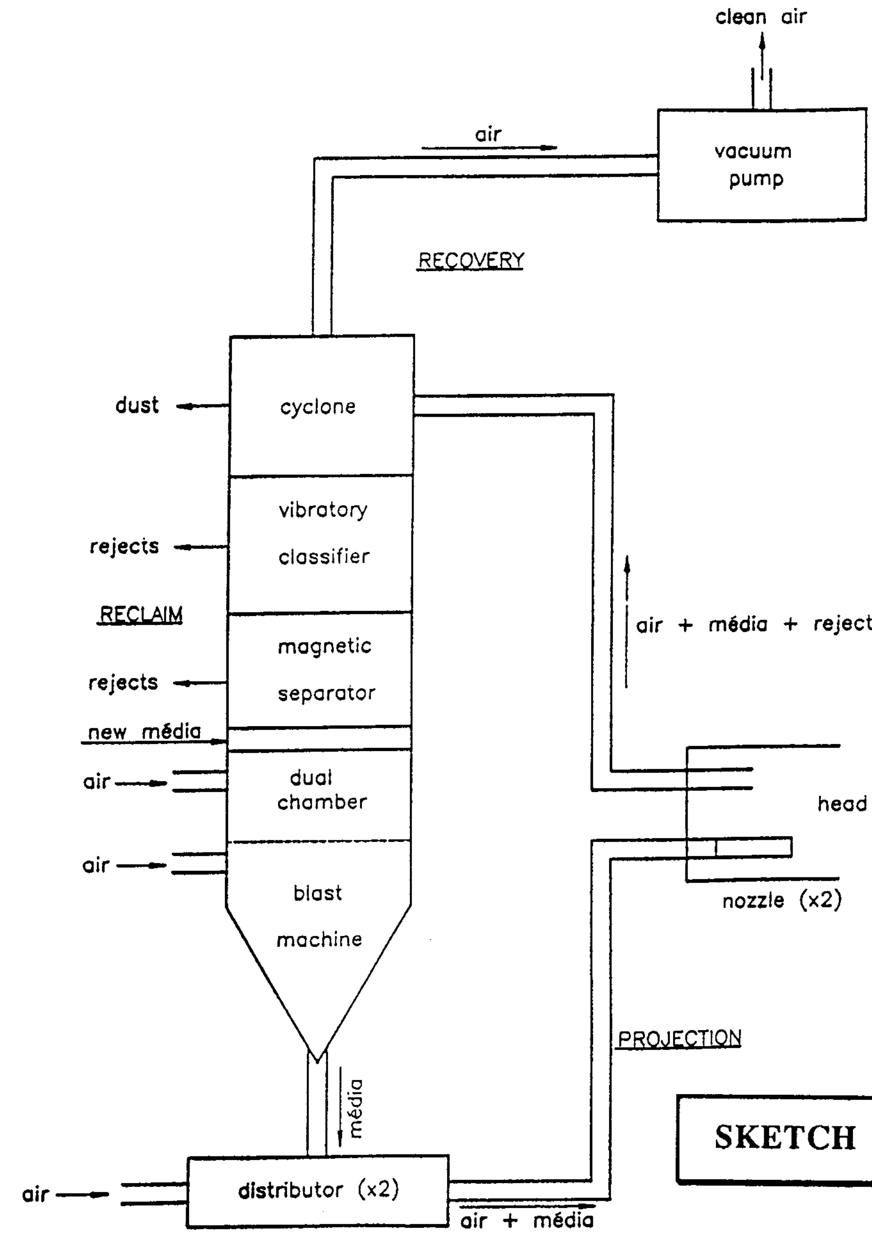
CENTRE INDUSTRIE

AUTOMATED TECHNOSTRIP SYSTEM
FOR STRIPPING LARGE SURFACES

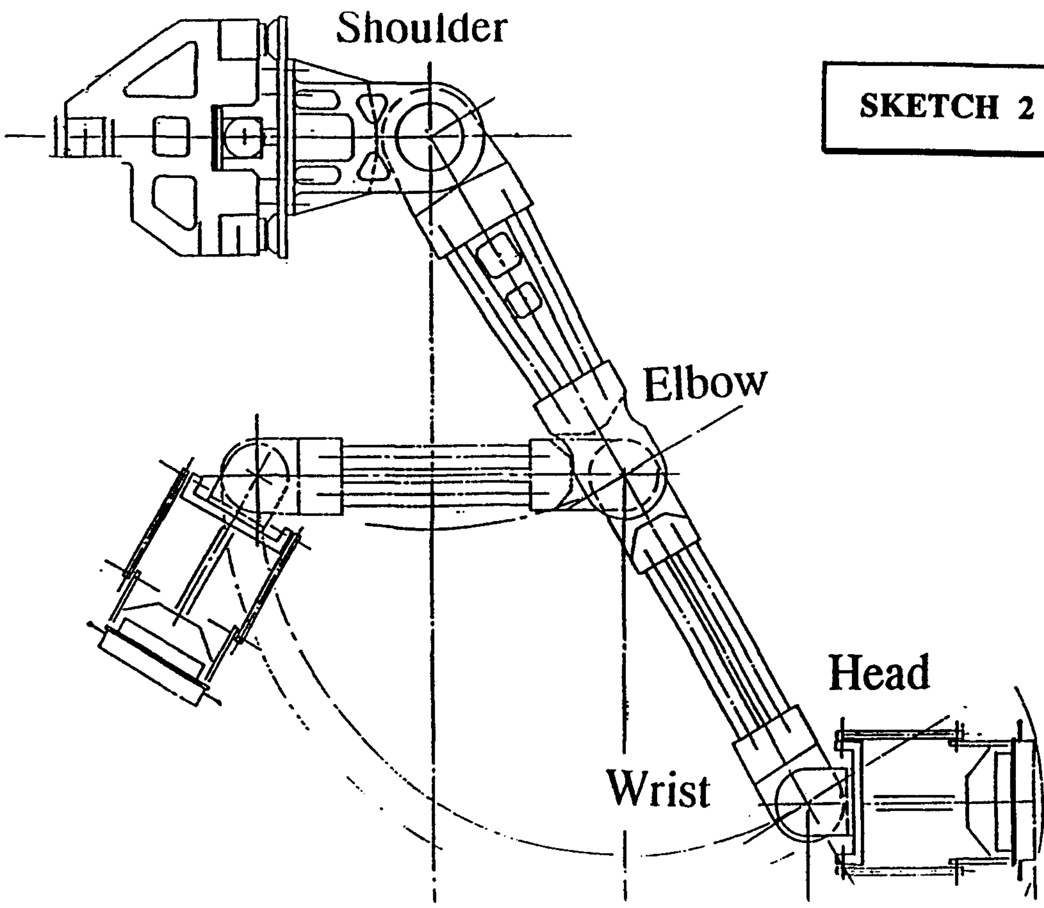


SKETCH 1

PROJECTION , RECOVERY AND RECLAIM SYSTEM

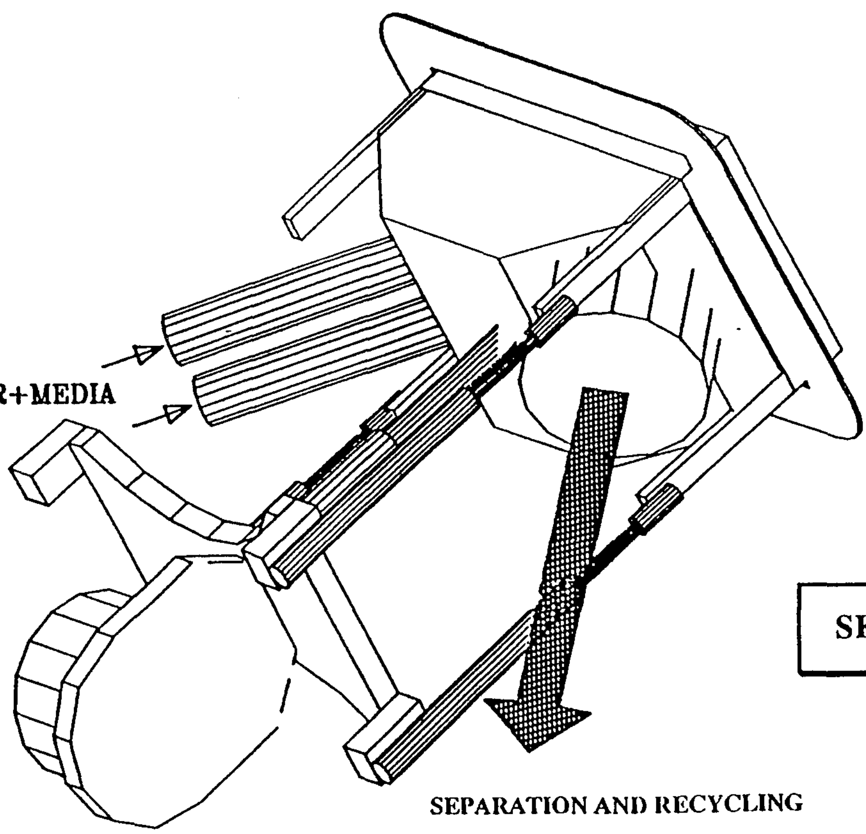


SKETCH 3



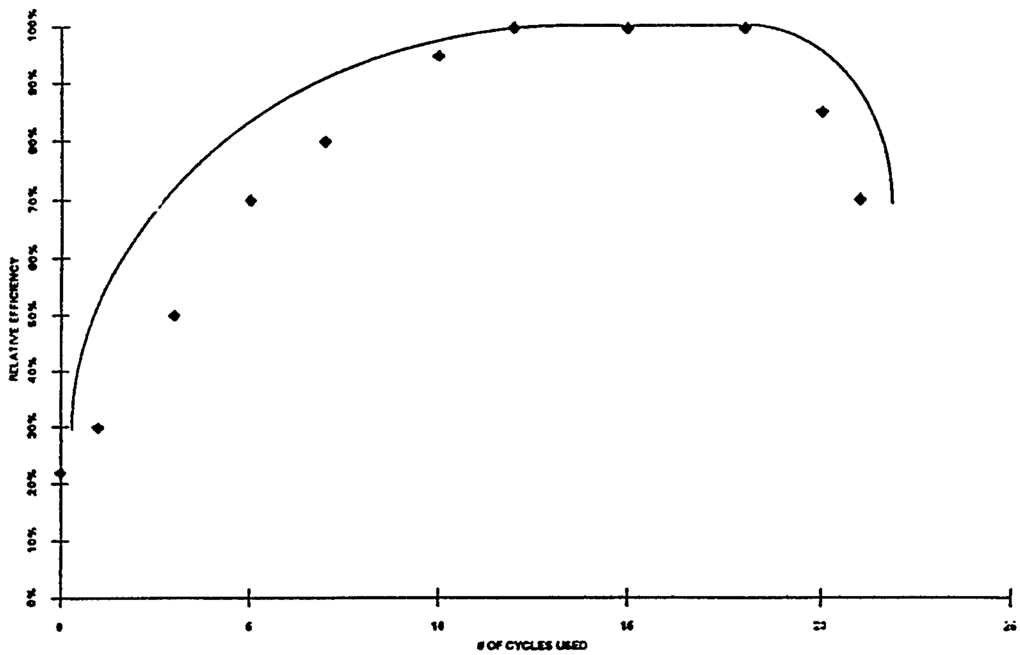
SKETCH 2

BLASTING AND RECOVERY HEAD



SKETCH 4

PAINT STRIPPING EFFICIENCY OF ENVIROSTRIP STARCH MEDIA

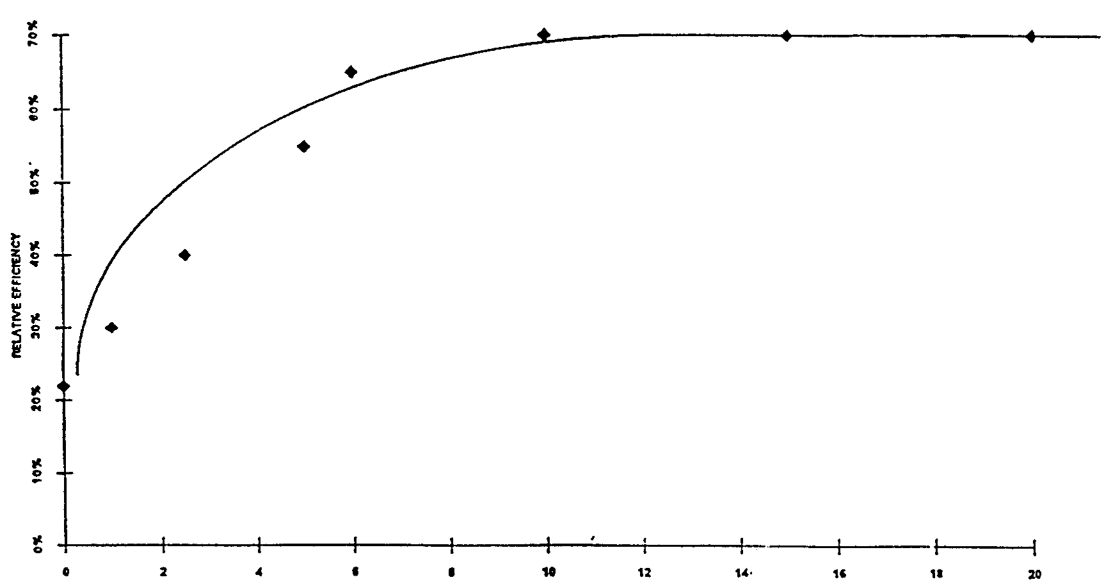


SKETCH 5

TECHNOSTRIP
ESTA INDUSTRIE

PAINT STRIPPING EFFICIENCY OF ENVIROSTRIP STARCH MEDIA

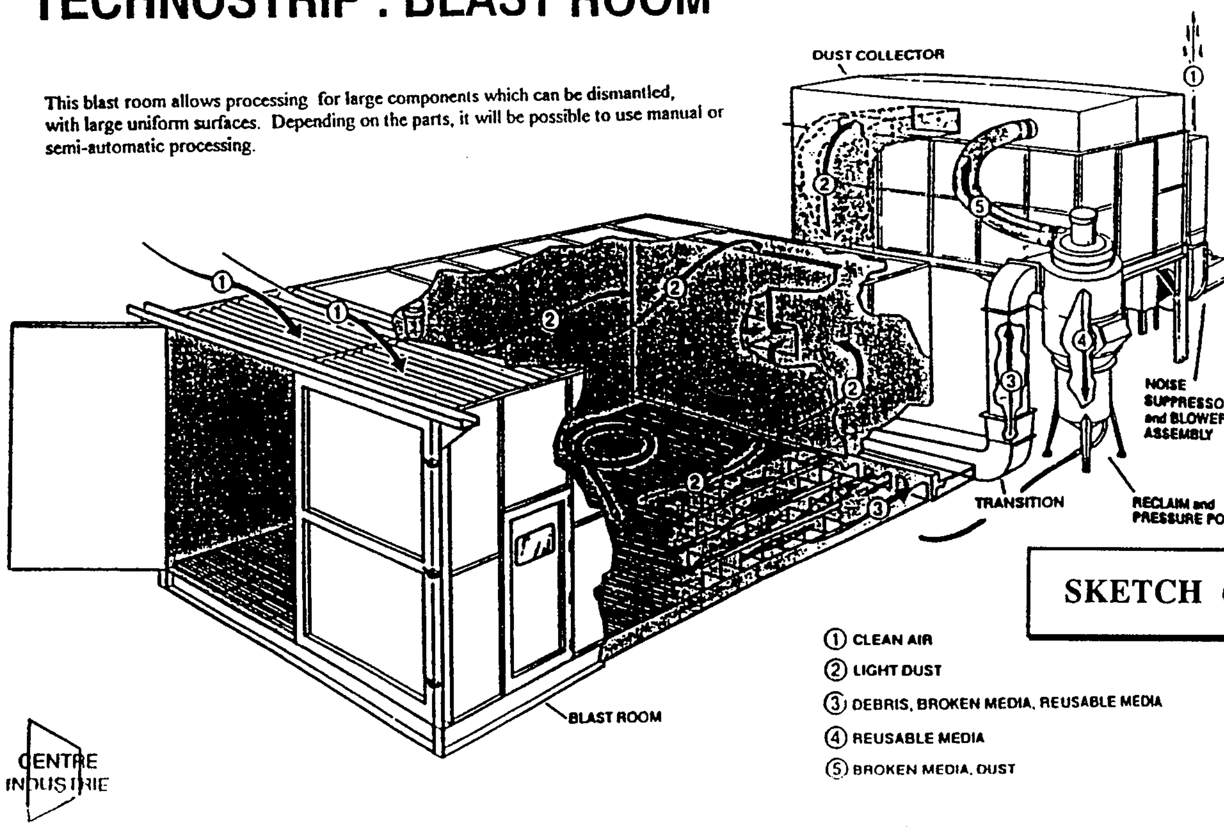
NEW MEDIA AUTOMATIC ADD



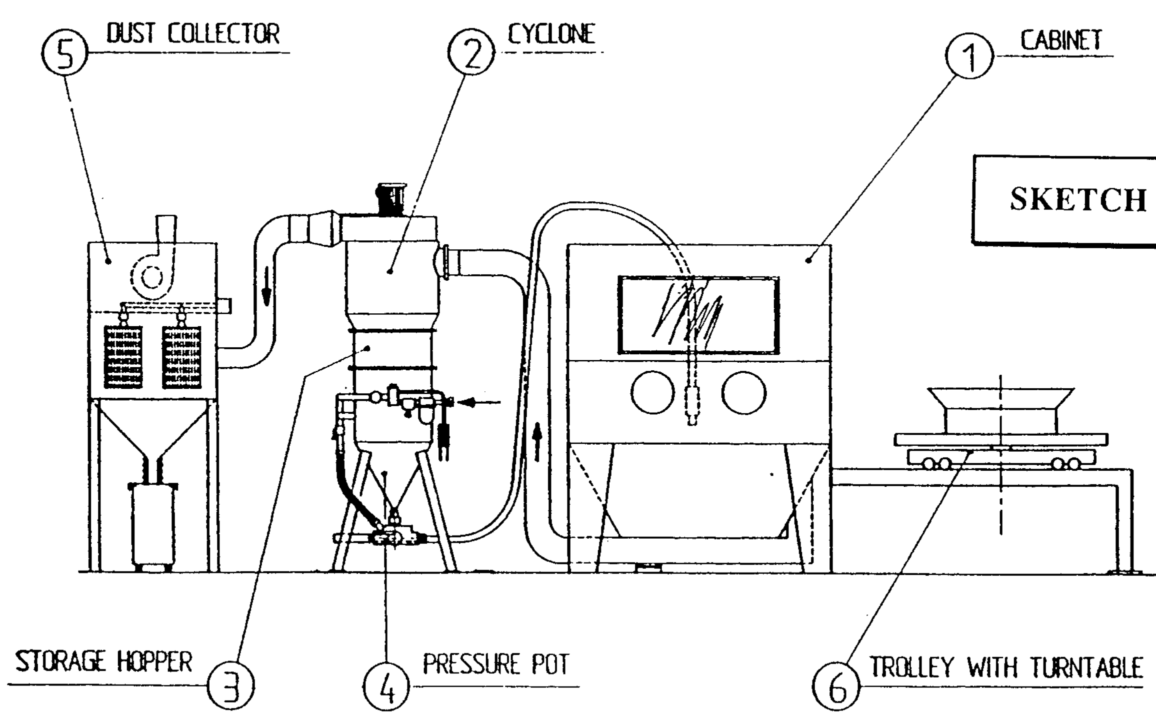
TECHNOSTRIP
ESTA INDUSTRIE

TECHNOSTRIP : BLAST ROOM

This blast room allows processing for large components which can be dismantled, with large uniform surfaces. Depending on the parts, it will be possible to use manual or semi-automatic processing.



SKETCH 6



SKETCH 7

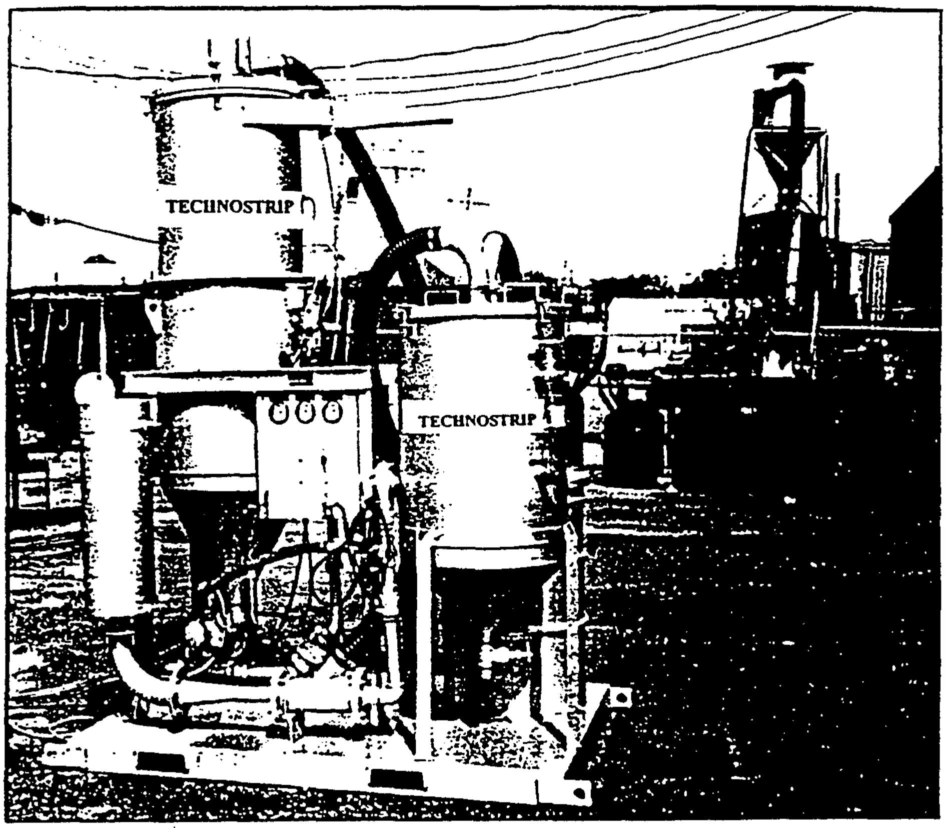
SKETCH 8

CENTRE INDUSTRIE

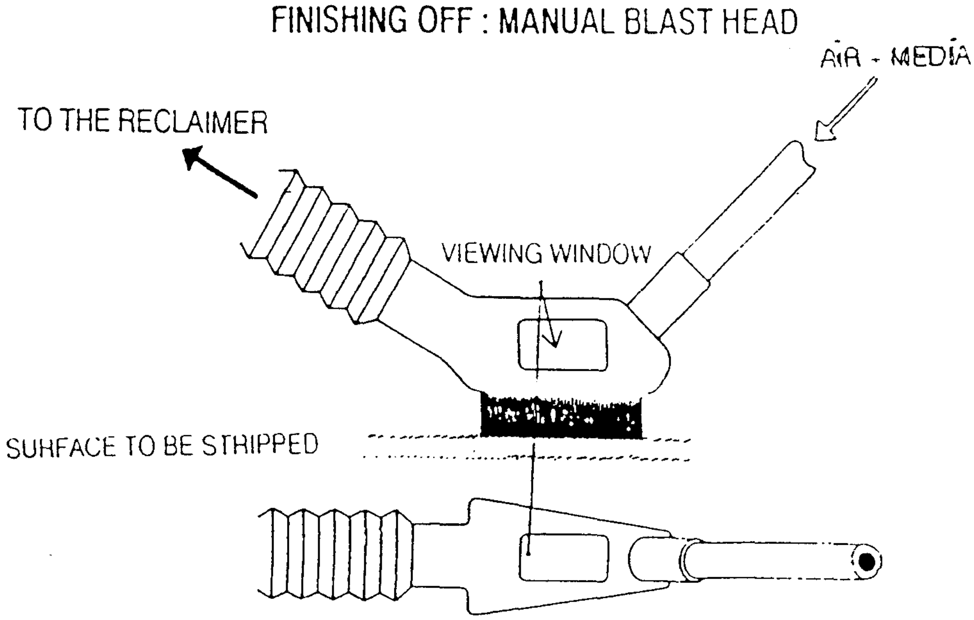
TECHNOSTRIP :

PORTABLE UNIT FOR MANUAL STRIPPING

The equipment allows manual closed circuit stripping for all surfaces that cannot be reached by the automatic system.



FINISHING OFF : MANUAL BLAST HEAD



WATER BLASTING PAINT REMOVAL METHODS

Dr. Terry Foster
Esquimalt Defence Research Detachment
FMO Victoria
Victoria, B.C., Canada V0S 1B0

SUMMARY

Water blasting is a paint removal technique that has been used for cleaning and paint removal for many years. The major disadvantages until recently were the slow rate of paint removal and the possibility of damage to the substrate from the high pressures used. With the improvement in nozzle design that allows for higher operating pressures and the use of environmentally compliant paint softeners or strippers, water blasting is becoming a recognized technique for paint removal in the aircraft industry.

1. INTRODUCTION

With the restriction and banning of most of the phenolic-based paint strippers, high and medium pressure water blasting are being developed as two of the possible replacement coating removal techniques. The medium pressure water blasting uses water pressures of 7,250 psi in combination with paint softeners. The high pressure water blasting is at pressures up to 28,000 psi but requires robotic control.

The medium pressure water blasting process utilizing chemical softeners is a commercial process owned by *LUFTHANSA* called *AQUASTRIP®*[1]. Although paint softeners add an extra step in the removal process, lower blasting pressures (7,250 psi) are used to remove coatings. The lower pressures mean a reduced possibility of impact damage to the substrate from the blasting process.

The Large Aircraft Robotic Paint Stripping System (LARPS) using high pressure water (up to 28,000 psi) is a process being developed by the USAF (Wright Laboratory, Aeronautical Systems Division (AFMC)) in conjunction with *United Technologies, USBI Co.*[2].

High and medium pressure water blasting offers several advantages:

- water is usually readily available
- water is inexpensive and easy to handle
- selective paint stripping feasible
- no media storage problems
- technology readily available for treatment and disposal
- media is readily recyclable
- only paint debris to remove in waste treatment process
- low capital investment

2. MEDIUM PRESSURE WATER BLASTING USING PAINT SOFTENERS

Medium pressure water jets utilizing chemical softeners is a commercial process owned by *LUFTHANSA* called *AQUASTRIP®*. The blast head for this process consists of two nozzles integrated into a rotating head. The head rotates at 2000-6500 rpm and is driven by an impulse from the water jets due to the eccentric alignment of the nozzles. The typical parameters used for this process are:

- maximum operating pressure - 7,250 psi
- water velocity - 320 m/sec
- water flow rate - 20 l/min
- traversal speed - 50 mm/sec
- standoff distance - 30 - 150 mm

The *LUFTHANSA AQUASTRIP®* program development findings has shown that up to 60% of all stripping jobs require the use of softeners. The chemical softeners are most effective with polyurethane coatings and the dwell times must be determined for each coating system. A dwell time of 2-4 hours is normal and a water rinse is used to remove the paint softener prior to water blasting. Two paint softeners are currently used *Turco 1270-5* and *Brent LB2020* and both are based on biodegradable solvents such as benzyl alcohol.

A research program was carried out to determine the

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

effects of the *AQUASTRIP®* process on the long term integrity of aircraft structures. These tests showed that the two softeners did not induce pitting or etching of aluminum (2024-T3) components and no degradation of elastomers was observed.

During dynamic operation for more than 20 cycles, no damage was found to clad or anodized layers but damage to these surfaces could occur if the nozzle was stationary for 5-10 seconds. Cadmium plating on fasteners was not removed by this process. Residual stress measurements using Almen Arc Heights showed deflections of less than 10 µm, well below the allowable limit of 150 µm for 2024-T3 aluminum. Fatigue test results indicated that under the above blast conditions there was no change in the fatigue life of the material.

Water migration during blasting can occur into cavities directly accessible for the water jet. Neutron radiography has shown that properly bonded or sealed surfaces are not affected by the *AQUASTRIP®* process. The *AQUASTRIP®* process can be quite destructive on seals and the seal removed if the jet is directed at the edge of the sealer.

Use of the *AQUASTRIP®* process on composite surfaces requires further refinement. It is recommended that a complete test matrix be developed for each composite material, prior to use of the *AQUASTRIP®* process. The application of the paint softeners used in the *AQUASTRIP®* process to composite surfaces has been approved by *LUFTHANSA* in prior test procedures.

3. HIGH PRESSURE WATER BLASTING

The USAF (Wright Laboratory, Aeronautical Systems Division (AFMC)) and *United Technologies, USBI Co.* are developing a Large Aircraft Robotic Paint Stripping System (LARPS) using a high pressure water process as an environmentally safe and effective paint removal system.

The robotic system is being developed independently of the high pressure water system. The robotic system will be designed to handle large military aircraft such as the Boeing C-135, B-52, E-3 and the Rockwell B-1B. Hanger type, aircraft preparation and system mapping may be different for each aircraft but the system will be essentially the same.

The procedure for qualifying a high pressure water blasting system has been broken down into three parts, I) Process Optimization, ii) Process Validation Testing, and iii) Additional Materials Testing. As of 1992, the process optimization has been completed and the process validation testing has begun.

The high pressure water blasting system under development uses blast nozzles designed by *USBI* that provide a uniformly distributed waterjet intensity that is sufficient to remove primer and topcoat but does not roughen the aluminum substrate to an unacceptable degree. The mechanism of coating removal is similar to that from rain erosion and modelling studies are underway to characterize the waterjet impact properties and allow refinement of the blasting parameters based on coatings characteristics.

The process optimization study resulted in the following parameters for use in the high pressure water process:

- maximum operating pressure - 24,000 psi
- water flow rate - 20 l/min
- traversal speed - 25 mm/sec
- standoff distance - 37 mm
- stripping rate - 1.25 ft^2/min per nozzle

Using the above parameters residual stress measurements using the Almen Strip method gave Almen arc heights of less than 75 µm for 2024-T3 aluminum alloy. Surface roughness measurements under the same blasting conditions resulted in surface roughness increasing from 23, 36, 67, 126 µin through four blast cycles on Al 2024-T3 alclad.

Further process validation studies are planned to include composite surfaces (glass fibre and graphite fibre), aluminum and fibre honeycomb structures, lap joints and fasteners to investigate sealant integrity and water intrusion.

4. CONCLUSIONS

The low pressure water blasting process in conjunction with paint softeners is an environmentally friendly technique for removing coatings. The technique also imparts no significant substrate damage on either clad or anodized Al 2024-T3 alloys.

The LARPS system looks promising for an automated high pressure water blasting system. The robotic system could also be used for various NDT inspection methods such as X-ray, ultrasonic or eddy current.

5. ACKNOWLEDGEMENT

The information provided in this paper was taken from two reports (see references 1 and 2) presented at the AGARD Workshop on *Environmentally Safe and Effective Processes for Paint Removal* (AGARD Report 791) held during the 75th meeting of the AGARD Structures and Materials Panel in Lindau, Germany from 7th-8th October 1992.

6. REFERENCES

1. J. Volkmar, "*AQUASTRIP®* - An Innovative Paint Removal Technology", Paper #13 presented at the AGARD Workshop on *Environmentally Safe and Effective Processes for Paint Removal*, AGARD Report 791, Lindau, Germany 7th-8th October 1992.

2. D.W. See, S.A. Hofacker, M.A. Stone and D. Harbaugh, "Large Robotic Paint Stripping (LARPS) System and the High pressure Water Process", Paper #11 presented at the AGARD Workshop on *Environmentally Safe and Effective Processes for Paint Removal*, AGARD Report 791, Lindau, Germany 7th-8th October 1992.

PAINT REMOVAL AND SURFACE CLEANING USING ICE PARTICLES

T. Foster
Defence Research Establishment Pacific
FMO Victoria
Victoria, BC, Canada V0S 1B0
S. Visaisouk
Ice Blast International Corp.
627 John St.
Victoria, BC, Canada V8T 1T8

SUMMARY

Research into the possibility of using ice particles as a blast medium was first initiated at Defence Research Establishment Pacific (DREP) in an effort to develop a more environmentally acceptable paint removal method. A paint removal process was also required that could be used in areas where normal grit blasting could not be used due to the possibility of the residual blasting grit contaminating machinery and other equipment. As a result of this research a commercial ice blasting system was developed by RETECH. This system is now being used to remove paint from substrates that cannot be easily blasted by conventional techniques and also to clean soiled or contaminated surfaces.

The problems involved in the development of an ice blast system, and its components and their functions are described. Due to the complexity of paint removal using ice blasting, parameters such as air pressure, ice particle size and ice particle flow rate were studied and adjusted to suit the nature of the particular coating and substrate of interest.

The mechanism of paint remove by ice particles has also been investigated. A theoretical model has been developed to explain the different paint removal mechanisms such as erosion by abrasion and erosion by fracture as they relate to ice blasting.

Finally, the use of ice blasting to removal paint from a variety of substrates is presented as well as examples of surface cleaning and surface decontamination.

1. INTRODUCTION

1.1 History of Ice Blasting

Ice blasting as a process for paint removal was first studied at DREP in the late sixties and early seventies. Initial experiments showed that ice particles could be accelerated by high pressure air and could be effective in removing paint from coated surfaces. A more systematic study of the effects of ice particle size, ice temperature, rate of mass flow, standoff distance and air pressure by G.W. Vickers[1,2] showed that ice blasting could be used to remove a variety of different coatings from metal surfaces.

In 1984 DREP contracted with RETECH to investigate developing the concept of ice blasting. During a series of contracts with RETECH the effects of nozzle design, ice particle size, ice particle size distribution and ice particle temperature on the rate of coating removal were studied and the ice blasting process refined.[3] In 1988, using Defence Industrial Research (DIR) funding, a commercial ice blasting system was developed by RETECH. Refinements since then have led to the current commercial ice blasting system.

1.2 Advantages of Ice Blasting

Ice blasting was conceived as a dust-free coating removal technique for confined spaces (tanks or void spaces) or areas where conventional blasting could not be used due either to safety considerations or the possibility of damage to equipment by the ingress of blast media (eg. bilge areas of ships). More recently ice blasting has developed into a coating removal and cleaning technique for substrates that could be damaged by conventional paint removal techniques

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

such as paint strippers and grit blasting.

The advantages of using crystalline ice as a blasting media as compared to other abrasive media such as grit, alundum or plastic are as follows:

1) ice is not abrasive and masking of most delicate surfaces is not necessary,

2) no dust is produced by ice breakdown thereby reducing the environmental impact of coating removal,

3) ice melts to water which can be readily separated from the coating debris thus simplifying disposal,

4) ice is easily made on site from water and electricity, reducing dependence on media suppliers, and

5) ice particles do not damage machinery or other equipment if contamination occurs.

1.3 Mechanism of Coating Removal Using Ice Blasting

Conventional blast media such as sand, grit or alundum rely on the abrasive quality of the blast media to erode the coating from the substrate. Ice is a non-abrasive blast media which fractures the coating rather than abrades.

How a coating is removed from a substrate depends upon the nature of the particles used (hard or soft, blunt or angular) and the nature of the coating (brittle or ductile, thick or thin).

Blunt particles have an elastic impact at low velocities, and an elastic-plastic impact as the velocity increases. Angular particles have an elastic-plastic impact. With hard or abrasive particles the elastic-plastic damage occurs primarily on the coating, while with soft or non-abrasive particles it occurs primarily on the particles - they disintegrate.

Coatings can be brittle or elastic. When subject to particle blasting, coatings generally behave as brittle materials. The erosion of coatings by soft or non-abrasive particles occurs through fracture or through plastic deformation or through abrasion when the velocity of the impact is too low to cause fracture. The erosion of coatings by hard and abrasive particles normally is the result of plastic deformation. Some newer coatings are chip resistant and thus quite elastic and difficult to remove by any method.

In abrasion, a particle impinges on the coating at an oblique angle. On impact, it creates a crater and a lip or rim of displaced material as shown in Figure 1. Further impacts remove the lip material and/or create large craters. As abrasion relies on brute force, it is non-discriminating and either some of the coating remains or some of the underlying substrate is removed or damaged (Figure 1).

Substrate erosion is not necessarily a negative effect. For example, its provides the surface profile necessary for good paint adhesion, especially for high build coatings on steel. Substrate erosion also removes chemically bound corrosion products prior to re-coating. However, in some other situations, substrate erosion or damage can lead to serious problems of structural integrity.

The fracture theory of coating removal is shown pictorially in Figures 2 and 3. On impact at normal velocities ice particles transfer energy to the coating producing conical cracks. At higher velocities, radial and lateral cracks are also formed. Loss of coating material from the volume element defined by the intersection of the various cracks produces "sombrero" structures (Figure 2). Further ice particle impacts tend to further the extension of the fracture lines along the coating/substrate interface (Figure 3) instead of creating more "sombreros". This is because crack propagation in this plane requires overcoming the adhesive force (mechanical bonds, hydrogen bonds, or van der Waals forces) which is much lower than the cohesive force (covalent bonds, ionic bonds or cross-linking) existing in the coating material or the substrate. Similarly creating new cracks in the coating or substrate requires more energy than extending the cracks along the plane between the coating and the substrate.

Evidence of the fracture mechanism came from microscopic examination of an ice blasted surface and the observation that during ice blasting, coatings were removed in large pieces the size of the nozzle diameter, or larger, rather than by methodical

abrasion of the coating. Microscopic examination of a coated surface after ice impact, but before complete coating removal, showed that the coating was covered with small cracks and in some small areas no coating remained (Figure 4). These observations led to the theory that ice particles remove coatings by way of a fracture mechanism rather than by abrasion. The theoretical considerations of ice blast phenomenon have been described in two previous reports.[4,5]

1.4 Mechanism of cleaning using Ice Particles

As ice is non-abrasive, it is ideally suited for cleaning applications where surface contaminants are to be removed from substrates, particularly delicate and fragile ones.

Although ice particles are non-abrasive, they provide physical agitation on impact. This mechanical rubbing action is sufficient to remove most non-bonded foreign matter. On melting the water serves to flush the surface free of debris.

Ice particles have also been found to be superior in removing surface contaminants from surface cracks and voids. This is likely attributable to the force developed by the physical deformation of the ice particles on impact.

2. ICE BLASTING APPARATUS

A schematic of the ice blasting equipment, consisting of an air conditioning module, ice making module and an ice conditioning module is shown in Figure 5.

Air from a compressor fitted with an aftercooler is diverted to two streams: about 15% of the air is dried and cooled down to -20 °C and the remaining is utilized unimproved. A single ice maker supplies ice at 90-115 kg/h; if more ice is required then several ice makers can be utilized. The ice is sized according to application. The size distribution is particularly dependent on the coating/substrate combination to be stripped. A precision metering fluidizer controls the ice particle flow rate. The instantaneous and continuous production, sizing, metering and fluidizing of the ice particles are constantly monitored and optimized by the ice management system to prevent ice packing, clogging and interrupted flow. The fluidized ice is delivered through an insulated transport hose to the blast nozzle which can be up to 80 m away. High pressure air is injected at the nozzle at pressures up to 200 psi.

Accelerating the ice particles at the nozzle reduces the volume of high quality air, (refrigerated and dried) required for ice blasting. This reduces the overall energy required for ice blasting drastically. The high pressure air and the ice particles are only in contact for a short period of time and little ice particle degradation has been observed.

3. EXAMPLES OF COATINGS REMOVAL AND CLEANING BY ICE BLASTING

The ice blasting equipment was operated in two modes, low pressure and high pressure. The blast parameters used in the following examples are shown in Table 1.

3.1 Coating Removal From Graphite Epoxy Composites

A graphite epoxy panel was coated with the standard Canadian Air Force coating system, 25 µm of a strontium epoxy primer and 50 µm of a polyurethane topcoat. The coating was allowed to cure at 20 °C for one week. This coating was readily removed from the substrate at both high and low pressures with no visual damage to the substrate. Coating removal rates of between 225 cm^2/min and 450 cm^2/min were recorded. A scanning electron microscope (SEM) examination of the substrate after blasting also revealed that there were no broken or exposed graphite fibres and the top layer of resin was still intact. The sharp edges of the paint are indicative of a brittle fracture in the paint.

3.3 Cleaning Of An Aircraft Polyurethane Topcoat

The aircraft epoxy/polyurethane coating system was also applied to an aluminum panel. The coating system was cured for one week at 20 °C and for one week at 65 °C. The coating was then soiled with a mixture of hydraulic fluid and carbon black which was cured in an oven at 75 °C for one hour. The excess soil was removed with a rag leaving a stained surface (Figure 6). The stains were easily removed using low pressure blasting with no visual damage to the coating surface (Figure 7).

3.4 Cleaning of Engine Components

Compressor blades, 7th stage, and turbine blades, 1st stage, from a JT9D engine from a commercial airliner were cleaned using ice blasting. All of the corrosion products and combustion products (Figure 8) were readily removed by ice blasting, thus increasing the efficiency of the engine. There was no damage to the underlying coating during the ice blasting process.

5. CONCLUSIONS

Ice blasting has been shown to have several advantages over conventional blasting processes. The amount of blast media used is small (~100 kg/h or 100 litres of water), and clean up and media contamination are either greatly reduced or eliminated. There is no need to store large volumes of contaminated media when removing toxic materials or hazardous coatings. The water can usually be separated from the coating quite readily and the water remaining can be further processed if required by reverse osmosis to reduce the volume of hazardous waste.

Ice is much softer and less abrasive than conventional media, and ice blasting can be used to remove paint from surfaces that would not tolerate conventional blasting media and processes. Ice blasting can also be used with little risk of damage or contamination of adjacent structures or equipment, due to the non-abrasiveness of the ice particles. For this same reason minimal safety equipment is required for personnel.

Ice blasting has been developed as a commercial process and has been used successfully to remove graffiti from polyurethane coating systems, to remove aircraft coatings from graphite epoxy composite structures and to clean soiled aircraft coating. Ice blasting has also been successfully used to clean corrosion and combustion products from gas turbine blades without damaging the underlying ceramic or metallized coating. More recently ice blasting has been used to clean tire and composite molds used in manufacturing, and has been used to clean food processing equipment.

5. REFERENCES

1. Vickers, G.W. and G. Galecki, "Development of Ice Particle Entrained Air Jets For Cleaning Purposes", DREP Contractors Report Series CR 83-30, April 1981.

2. Foster, T., and G.W. Vickers, "Use of Ice Particle Entrained Air Jets for Cleaning Purposes", 7th Internaval Corrosion Workshop, Canberra, Australia, April 1984.

3. Foster T., S. Visaisouk and R. Rowe, "Alternate Blasting Materials: Plastic Grit and Ice Particles", 8th Internaval Corrosion Conference, Plymouth, U.K., April 1988.

4. Visaisouk S., and S. Levine, "Theoretical Considerations of Impact Damage by Ice Blast: An Overview", DREP Contractors Report Series CR 89-31, December 1988.

5. Visaisouk S., and S. Levine, "Theoretical Considerations of Ice Blast Phenomenon with Experimental Correlation", Contractor Report Series CR 91-30, November 1991.

6. Benson, C.E., R.G. Grubb, R.C. Heller, B.D. Patton and G.L. Wyatt, "Crystalline Ice Blast Decontamination Technology Demonstration", presented at the Nuclear and Hazardous Waste Management International Topical Meeting", Boise Idaho, August 23-27, 1992.

TABLE 1 -- BLASTING PARAMETERS

Blast Parameters	Low Pressure Ice Blaster	High Pressure Ice Blaster
Input Air Pressure	80 psi	185 psi
Blast Air Pressure	80 psi	185 psi
Blast Air Temperature	25 °C	25 °C
Blast Air Volume	145 CFM	180 CFM
Ice Particle Size	3/16" - 1/4"	5/32"
Ice Particle Feed Rate	150 LB/HR	150 LB/HR
Standoff Distance	10-15 cm	7-12 cm
Angle of Blasting	75-90°	~90°

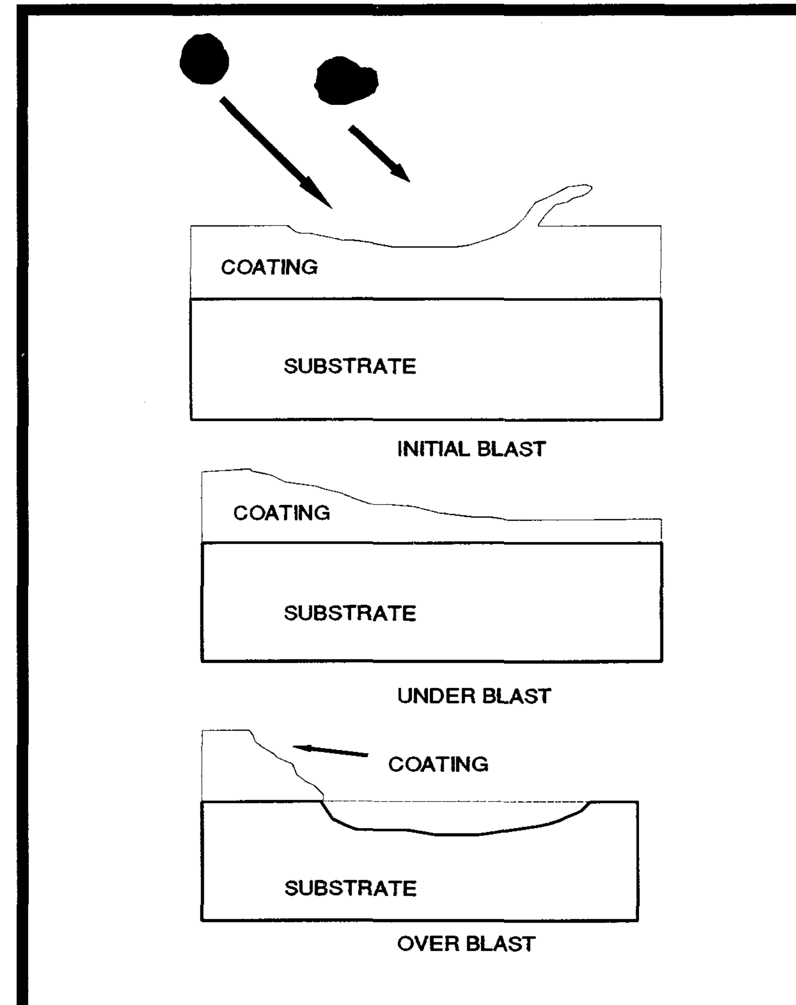


Figure 1 -- Coating Removal By Abrasion.

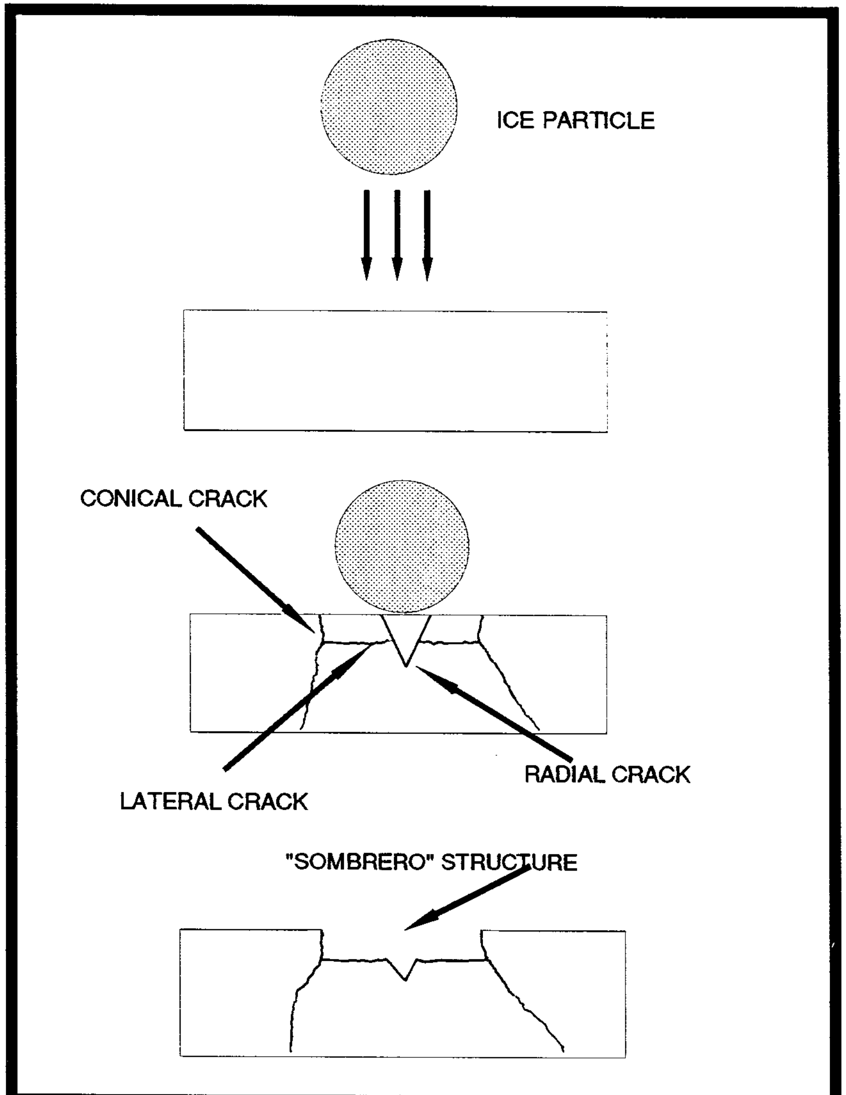


Figure 2 -- Crack Formation and Erosion by Fracture.

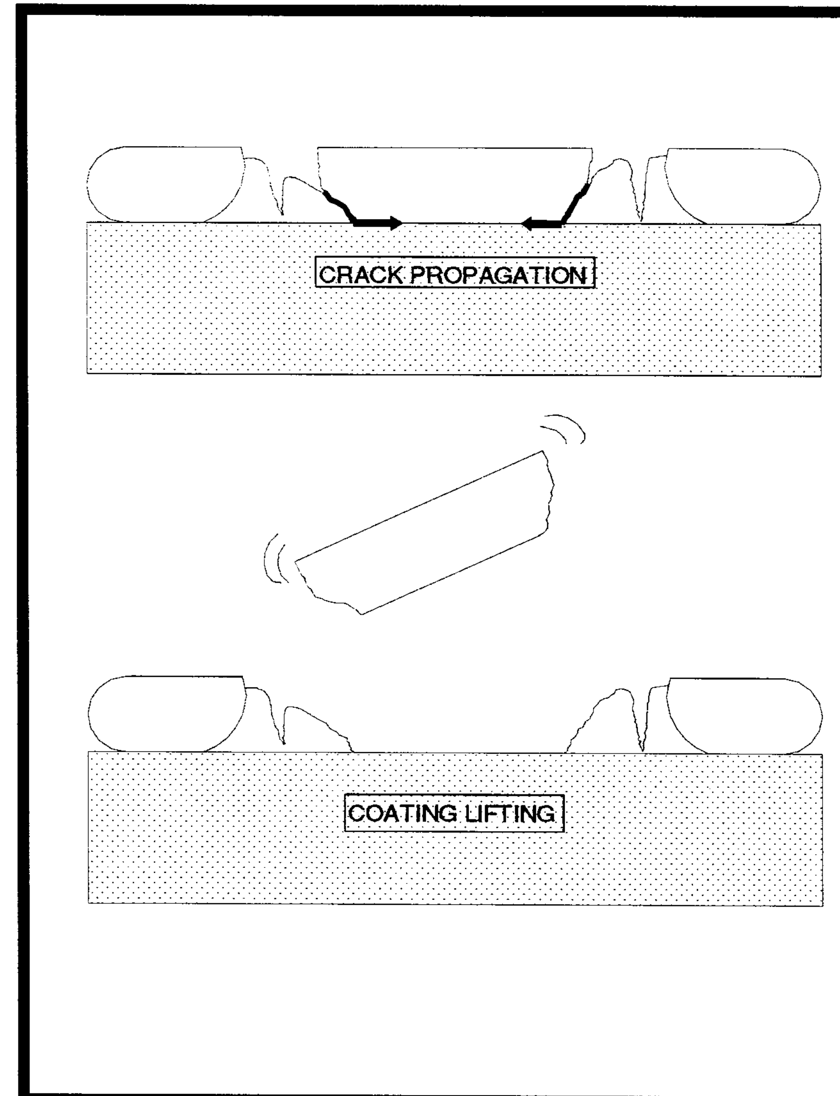


Figure 3 -- Crack Propagation and Coating Lifting.

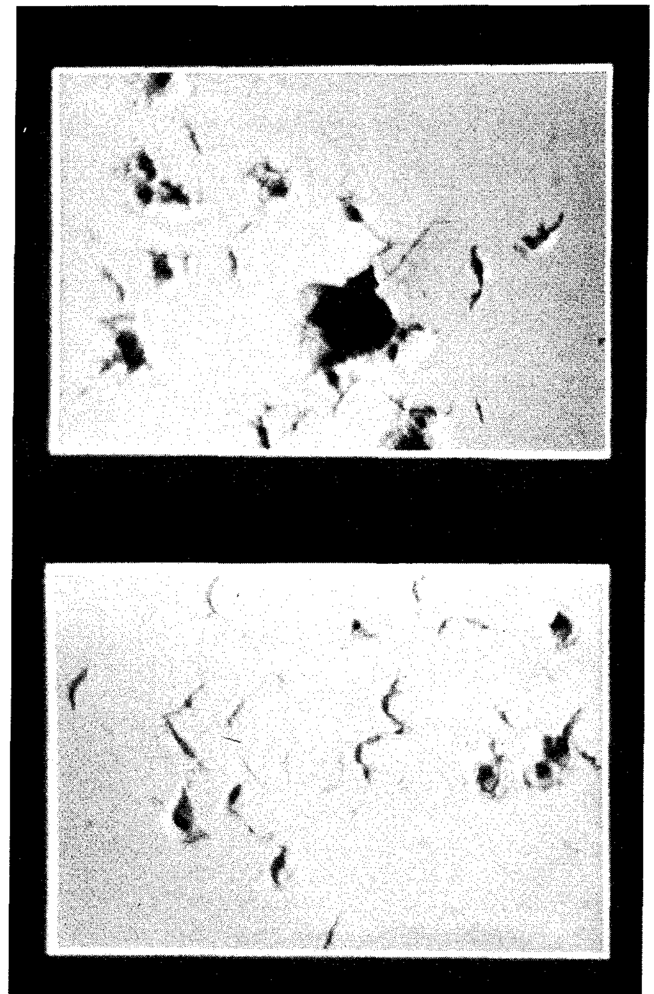


Figure 4 -- Surface Cracks Due to Ice Particle Impact.

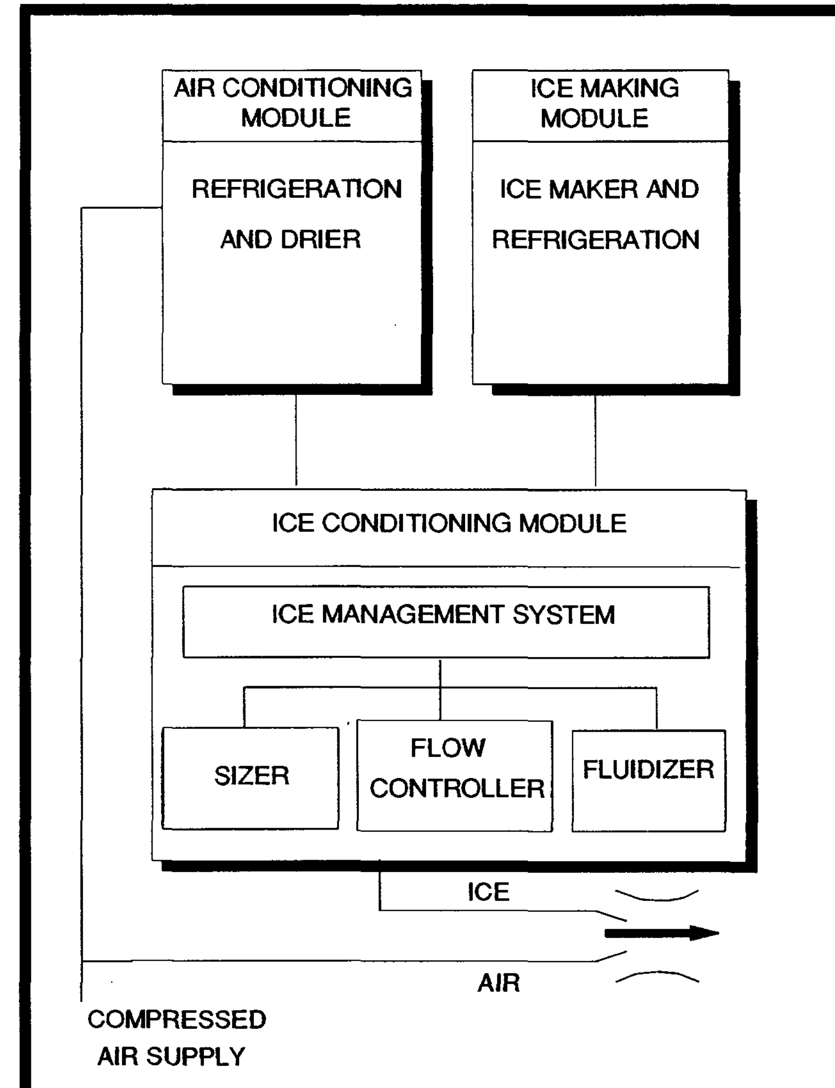


Figure 5 -- Schematic of Ice Blasting Equipment.

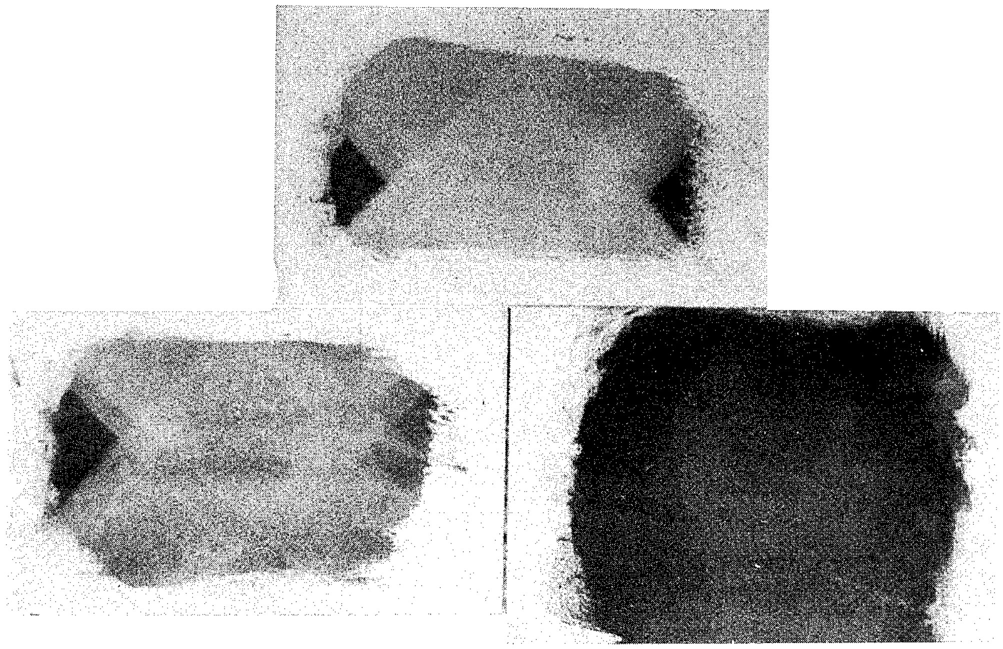


Figure 6 -- Soiled Aircraft Coating System Before Ice Blasting.

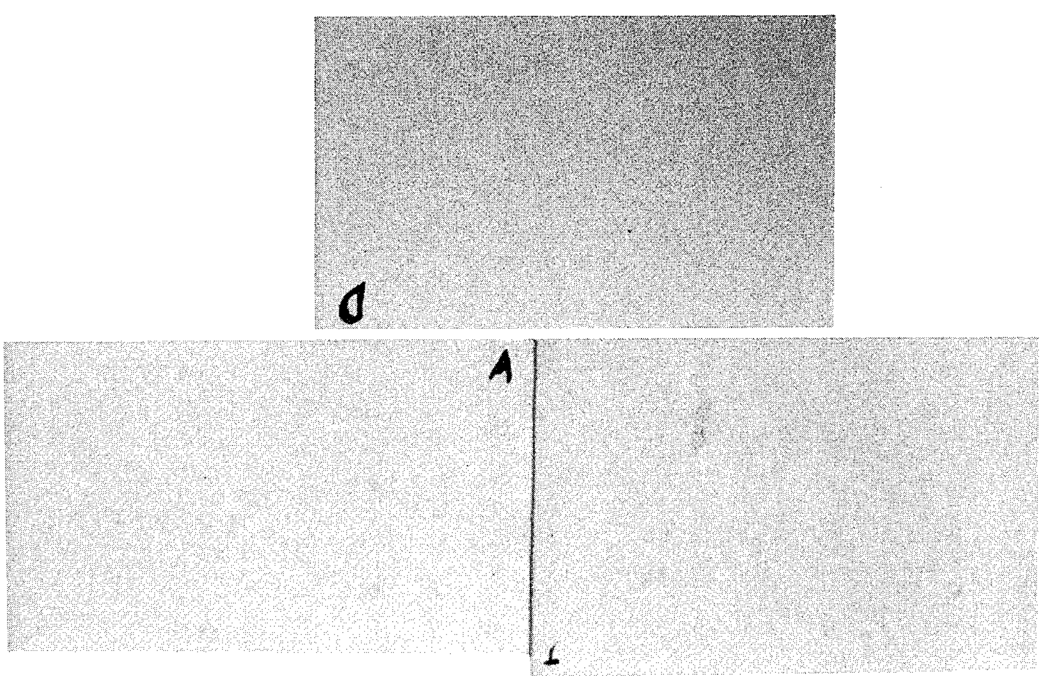
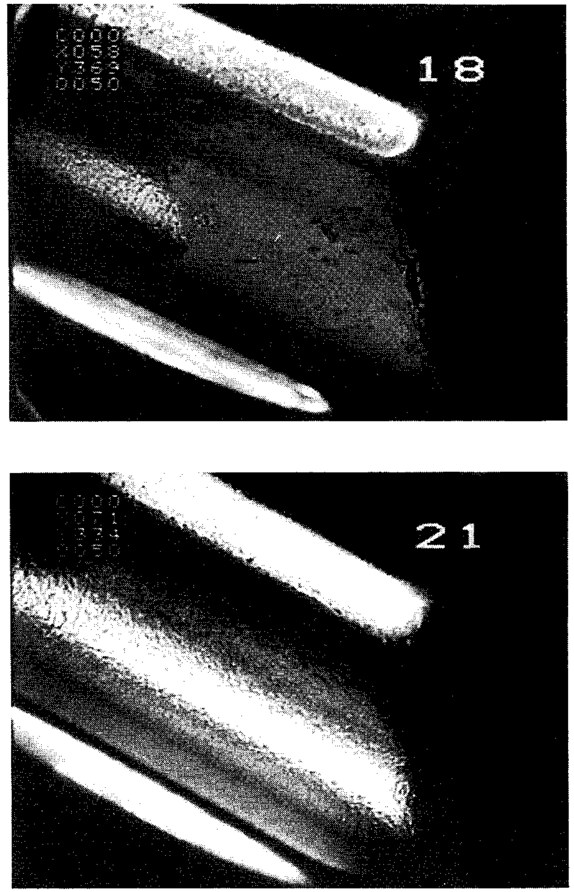
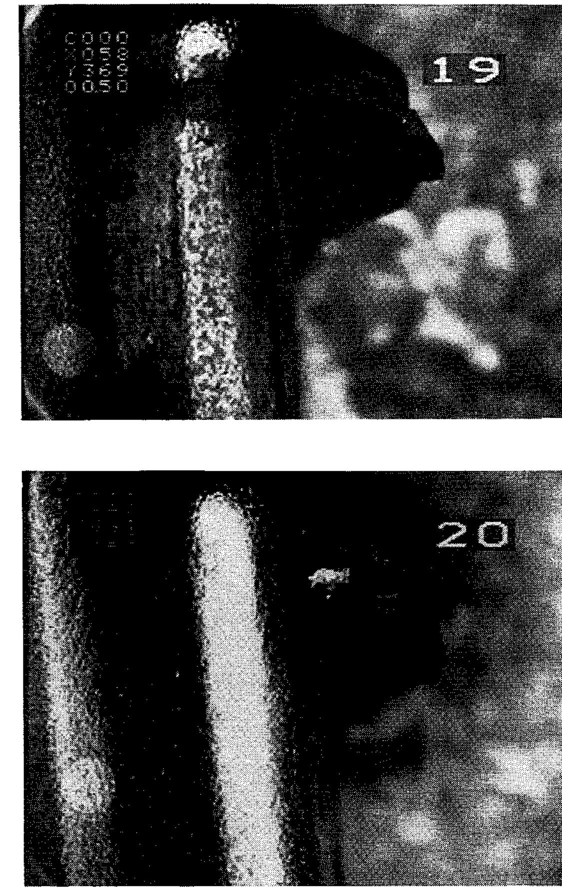


Figure 7 -- Soiled Aircraft Coating System After Ice Blasting.



JT9D Engine
Compressor Blade, 7th Stage
Top: before Bottom: after Ice Blast

Courtesy Japan Airlines



JT9D Engine
Compressor Blade, 8th Stage
Top: before Bottom: after ice blast

Courtesy Japan Airlines

Figure 8 -- Engine Components Before and After Cleaning With Ice Blasting.

Stripping with Dry Ice

Mr. Olivier Malavallon
Aérospatiale
Direction des Etudes
A/DET/CG-MP
Toulouse Est. 316 route de Bayonne
31060 Toulouse Cedex 03
FRANCE

1 - GENERAL PRINCIPLE OF PROCESS

Mechanical-type stripping using dry ice (solid CO_2) consists in blasting particles of dry ice onto the painted surface. This surface can be used alone or in duplex according to type of substrate to be treated.

2 - PRINCIPLES OF PROCESS

According to operating conditions, three physical mechanisms may be involved when blasting dry ice particles onto a paint system.

2.1 Thermal shock

The thermal shock generated by a sudden change in the temperature on the surface compared with the temperature within the thickness of the part, creates a tensile stress proportional to the temperature difference.

If this stress is greater than the breaking stress of the paint, a crack network develops on the surface and the paint becomes fragile.

2.2 Differential thermal contraction

If two materials are cooled to same temperature and subjected to movements, a difference in stress may appear at the interface between the two materials (for example at substrate/paint interface).

Note:
Most organic materials become vitreous at low temperatures, this makes the combined actions of thermal shock and differential thermal contraction more efficient.

2.3 Mechanical shock

The dry ice particles are blasted by a pressurized air jet onto the surface to be treated. The results obtained depend, on the one hand, on the characteristics of the media (temperature, grain size, hardness, density, etc.) and, on the other hand, on the blasting parameters (angle, distance, particle speed, nozzle, flow rate, etc.).

The efficiency of this stripping is reinforced when the paint has been previously made fragile.

3 - PARAMETERIZATION

The following parameters influence the stripping quality and, in particular, the uniformity and efficiency obtained.

3.1 Blast nozzle

Several types of nozzles exist. They differ by their geometries and dimensions. The results obtained can depend on the type of paints or protections removed. However, nozzles with flat outlet sections seem to offer better performances.

3.2 Nozzle travel speed

Stripping efficiency is reduced when travel speed is increased. If speed is too low or even null, the substrates may be damaged especially if they are of the composite type. Consequently, stops are prohibited.

3.3 Blast angle

The blast angle affects the mechanical shock. The force applied to the surface is higher as the angle tends towards 90°. However, best results are obtained for angles of between 60° and 80°.

3.4 Stripping distance

The lower the distance, the higher the shock. However, in order not to damage composite substrates, a minimum distance is to be observed.

3.5 Compressed air pressure and media flow rate

The flow rate is not measured at nozzle outlet but at ice particle storage tank outlet.
The higher the pressure and flow rate, the higher the kinetic energy of the particle jet.

4 - USE

The process and equipment studied are industrialized in the USA by COLDJET and in France by SIAC.

4.1 Equipment and technology

A heat exchanger is used to cool the liquid CO2. It is stored in a buffer register then transferred to the ice particle production unit (pelletizer). The pressure of the liquid CO2 is reduced to produce solid CO2 and gaseous CO2 (exhausted into the atmosphere).

The ice is compressed and stored in a hopper, adjusted in height, at a temperature of -80°C at atmospheric pressure. The CO2 pellet valve is located under the hopper.

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

4.2 Stripping

When performed manually, this process requires accurate handling by the operator. In effect, the operator adjusts the following parameters by his movements and position:

- travel speed of nozzle over the surface,
- blast angle,
- stripping distance.

Note:
Duplex-type industrial configurations exist where the parameters are previously set or controlled by automated systems (FLASHJET).

5 - TESTS PERFORMED

5.1 - Test specimens

- For metallic substrates, the test specimens were made of clad 2024 T3 aluminium alloy painted with a currently used scheme.

- For composite substrates, the test specimens were made of monolith epoxy carbon (6 tape plies), sandwich (4 fabric plies for skin), painted with standard schemes different for each type of structure. The paints applied were aged to different stages.

The surface areas of these test specimens ranged from several hundreds of cm^2 to 1 m^2.

5.2 Operating processes

During the stripping tests, the materials and the settings were made by specialists from SIAC.

From experience acquired, two configurations were retained:
- one simplex configuration, the process alone,
- one duplex configuration with previous application of a chemical product.

5.3 Inspections

Monitoring and inspections performed were visual or used magnification means. Their aim was to assess the following criteria :
- efficiency,
- quality obtained,
- selectivity,
- damage to substrate,
- substrate.

6 - RESULTS

6.1 - Simplex configuration

Stripping of a completely cured paint was almost impossible irrespective of the substrate. However, risks of damaging composite structures exist in certain configurations.

For fresh or recently applied paint (several hours), complete stripping can be obtained irrespective of the substrate. However, certain precautions must be taken for composites.

6.2 - Duplex configuration

Prior application of chemical products such as paint softeners allow the upper coats to be made fragile and damaged. According to the paint schemes considered, partial stripping can be obtained.

However, observed productivity was low and several hours were required to apply softeners.

6.3 - Comments

The equipment used generated a lot of noise (> 90 dB) and high amounts of gaseous CO2 were given off and had to be exhausted.

Also, in the configurations tested, the equipment handled by the operator was heavy, cumbersome and unsuitable for stripping surfaces on civil transport aircraft.

7 - CONCLUSION

Used alone and under the conditions in which it was tested, the characteristics and results of CO2 pellet blasting stripping were very poor. However, certain applications such as surface preparations or fresh paint stripping merit further examination.

Aquastrip

Mr. Olivier Malavallon
Aérospatiale
Direction des Etudes
A/DET/CG-MP
Toulouse Est. 316 route de Bayonne
31060 Toulouse Cedex 03
FRANCE

The AQUASTRIP stripping process is a mechanical process. It consists of applying a high-pressure water jet by means of a rotating stripping head with two water jets.

The efficiency of these water jets is improved in certain cases by using a paint softener before applying the water jet process.

This process has been developed and is industrialized by the German airline Lufthansa.

1 - PRINCIPLE OF PROCESS

The AQUASTRIP stripping principle consists in periodically applying (frequency 150 to 220 Hz) pressurized water by means of a rotating nozzle.

The physical high-pressure water jet paint stripping mechanism consists in mechanical shock and infiltration of the water between the various coats of the paint system.

The higher the kinetic energy of the jet, the higher the mechanical shock. Speed and water pressure must therefore be sufficiently high.

The mechanical shock (periodic in this application) causes the paint to crack and become fragile.

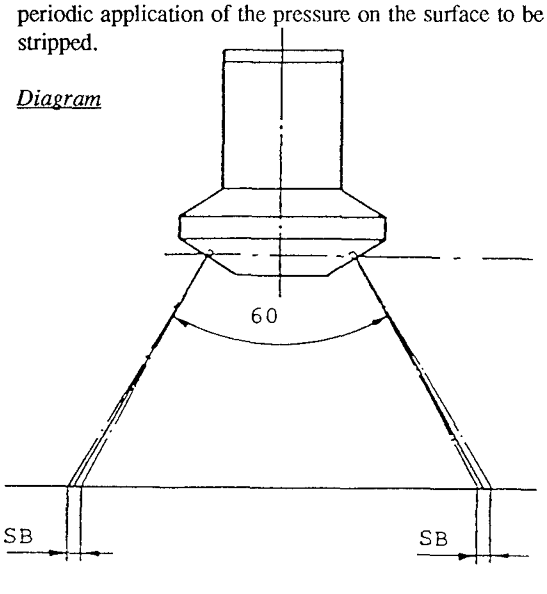
The water then infiltrates into these cracks and causes lack of cohesion between the coats of paint.

2 - STRIPPING HEAD PRINCIPLE

Stripping head principle

The stripping head includes two nozzles through which two water jets are blasted. The head is rotated by the pressure of the jets (or by its reaction force). This leads to periodic application of the pressure on the surface to be stripped.

Diagram



3 - PARAMETERIZATION

The parameters used are those conventionally retained to parameterize mechanical particle blasting stripping processes.

The main parameters influencing jet efficiency are as follows:

Simplex mode process (mechanical effect alone)

- nozzle/part distance (around 30 mm),
- water pressure (100 to 600 bar),
- water temperature (20 to 80°C),
- blast frequency (150 to 200 Hz),
- blast angle is fixed at 30°.

Duplex mode process (combined chemical and mechanical effects)

The parameters relevant to softener application must be considered:

- application temperature: 15 to 25°C,
- application time: 1 to 4 h,
- type of softener: - TURCO 1270-5
  - BRENT LB2020

Several comments are required concerning certain parameters.

Blasting frequency

The jet applied to the surface by nozzle design can be adjusted to produce a contraction/expansion phenomenon of varying frequency.

Stripping distance

The lower the distance, the higher the impact of the jet on the paint and the easier the stripping.

A variation of 10% in stripping distance is sufficient to change the stripping characteristics.

Pressure

This pressure acts:

- on the force exerted by the jet on the paint; the higher the pressure, the more aggressive the stripping,
- on stripping quality: stripping selectivity and uniformity are reduced when the pressure is increased.

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

Nozzle travel speed

The nozzle travel speed influences:

- stripping selectivity: paint thickness removal is reduced when speed is increased. Speed is therefore lower for stripping down to substrate than when stripping down to primer,
- stripping uniformity: reduced when speed is increased.

4 - USE

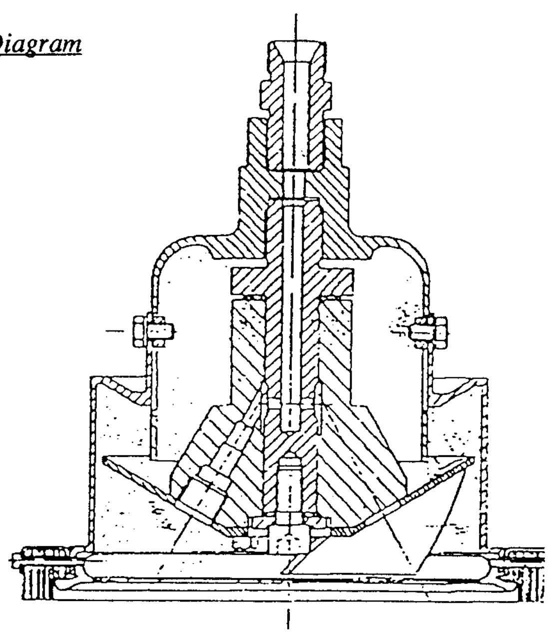
4.1 - Installation

The installation available at Lufthansa allows the AQUASTRIP process to be used with two equipment configurations.

1st configuration

A stripping room equipped with a manual stripping system with two rotating water jets.

Diagram



The inclination of the water jets with regard to nozzle centerline allows rotational speeds of around 3500 rev/min to be obtained.

- the water is recovered at floor level by a channel drainage system.
- a retreatment system filters the water by eliminating the paint waste obtained.
- a water circulation system recycles the water which is used in closed-circuit configuration.

2nd configuration

An automated hangar allowing maintenance operations is equipped with 6 automatic working platforms. A motorized manipulator is equipped with 6 stripping heads consisting of faired rotating heads designed along the same principle as the manual head.

This stripping assembly is installed on a telescopic platform allowing access to the greater part of the surface of an aircraft. A semi-automatic device controlled by the operator allows remote-control of head/substrate distance.

High-pressure system

Water is supplied by the urban network and initially pressurized to a pressure of 6 bars. An 8-piston pump then pressurizes it to 500 bars.

Retreatment system

A special drainage system allows separate treatment of water contaminated by softener and water used with the AQUASTRIP process alone. The water used by this process is directly treated in a separator/settler and stored in a reservoir for reuse. The water can be recycled around three times.

4.2 - Operating method

The AQUASTRIP process uses a specific operating process.

Step 1: Measurement of paint thicknesses on aircraft

The procedure consists in measuring the thickness of the paint coat over the complete surface of the aircraft. The measurement points are accurately located and a separate measurement is made for fuselage, wings and tailplane.

Step 2: Masking

The aim of the masking operation is to protect:

- parts which must be protected when applying softener:
  . composite parts,
  . edges of metallic bonded seals,
  . all moving parts,
  . the electrical equipment, etc.,
- substrates or composites which must not be stripped by the AQUASTRIP process.

Step 3: AQUASTRIP stripping process

Step 4: Cleaning of the surface

Step 5: Demasking

5 - RESULTS

The AQUASTRIP process has been subject to many studies conducted by Lufthansa in relation with manufacturers BOEING and AIRBUS Industrie.

5.1 - Evaluation on metallic substrates

The test specimens were as follows:

- clad 2024 material, thickness: 0.83 and 1.3 mm,
- paint system: epoxy primer + polyurethane top coat.

Test conditions for optimized process were:

- water pressure	:	500 bar
- water temperature	:	20°C
- nozzle/part distance	:	30 mm
- travel speed	:	50 mm/s

The analyses of the various studies showed that under certain conditions:

- the process does not reduce fatigue life,
- repeated stripping is possible up to 5 cycles without damaging the substrate (with a thickness of 0.83 mm),
- the process has no effects on permanent deformation,
- the process has no effects on paint adherence,
- the process does not damage bonded seals,
- selective stripping and complete stripping are possible,
- the softeners used have no effects on aluminium substrate corrosion.

5.2 - Restrictions in the use of AQUASTRIP

- Operators using AQUASTRIP must be highly qualified in the use of this process.
- Composite material parts must not be stripped with the AQUASTRIP process.
- The substrate is extensively damaged by prolonged stripping caused by a stop in stripping head movement.

5.3 - Approval of process by manufacturers

At present, the AQUASTRIP process is authorized by BOEING («No technical objection» document of 1990). AIRBUS Industrie has defined application limits for the AQUASTRIP process (Basic Process Definition).

This process can be used on aluminium, steel and titanium material parts and on metallic parts with bonded seals.

Stripping by Laser

Mr. Olivier Malavallon
Aérospatiale
Direction des Etudes
A/DET/CG-MP
Toulouse Est. 316 route de Bayonne
31060 Toulouse Cedex 03
FRANCE

1 - PRINCIPLE OF PROCESS

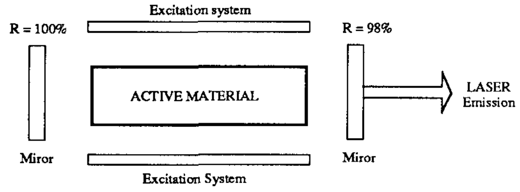
1.1 - Laser beam

LASERs (Light Amplification by Stimulated Emission of Radiation) are monochromic electromagnetic wave generators whose directivity, intensity and phase coherence characteristics have special properties.

A LASER beam generator consists of the following components:

- an active material: solid, gaseous or liquid,
- a luminous or electrical system exciting the active material,
- an optical system consisting of two mirrors, one reflecting by 100%, the other semi-reflecting (R ~ 98%)

Diagram :



The excitation system places the active material in a condition which causes LASER emission. When triggered, the light moves to and for in a cavity with two mirrors in LASER axis. As one of the mirrors is semi-reflecting, a part of the light passes through it. This is the usable LASER beam.

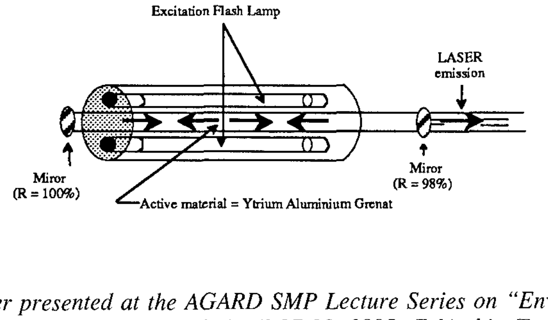
Three types of laser beam generators were evaluated.

1.2 - YAG LASER

The active material consists of a Yttrium-Aluminium-Garnet bar supporting neodymium Nd3+ ions which generate the LASER effect.

The bar is generally cylindrical (dia. 7 x L 210) and is excited by flash lamps (similar to photoflash units).

Diagram :



Two types of YAG LASER were evaluated

Make	Maximum power	Wavelenfth	Frequency	Pulse duration
Quantel	20 W	1,06 µm (IR)	30 Hz	10 ns
IQL 30	900 W	1,06 µm (IR)	100 Hz	10^5 à 10^6 ns

The power of the Quantel YAG LASER is low (20 W) but it has the advantage of being compact and light (3 kg).

The IQL YAG LASER has a power compatible with industrial applications such as stripping or welding. Use of optical fiber allows this LASER to be combined with a robotized arm.

1.3 - CO_2 TEA LASER

The active material is CO_2 gas. This material is excited by an electronic discharge within the gas.

The performance of the CO_2 TEA LASER used are given in the table below:

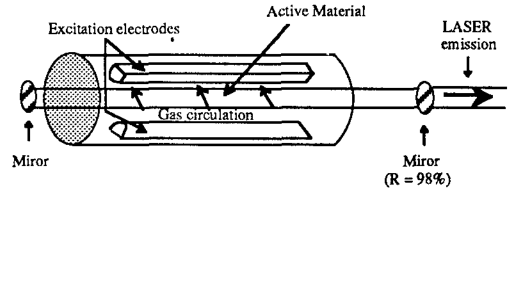
Make	Maximum power	Wavelength	Maximum energy	Maximum frequency	Pulse duration
Coherent-Hull	60 W	10,6 µm (IR)	5 J	12 Hz	90 ns

1.4 - Excimer LASER

The active material is gaseous, composed of a noble gas (Xe, Ar) and a halide (Cl, F).

Once excited by an electric discharge, these atoms group together to form excimers (EXCIted diMERs). These dissociate and generate the LASER effect.

Diagram



Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

The performance of the evaluated Xe Cl gas LASER are given in the table below:

Make	Maximum power	Wavelength	Maximum frequency	Pulse duration
Lumonics	100 W	308 nm (UV)	500 Hz	20 ns

The Excimer LASER is the latest generation LASER. The powers available today do not exceed 150 W. However, work is in progress on a 500 W to 1 kW LASER which will allow their application fields to be extended.

2 - STRIPPING

The main aim of stripping is to break the molecular bonds of the paint in order to separate it from the substrate.

2.1 - Stripping with YAG LASER (1.06 µm)

YAG LASER stripping can be explained by a thermal model. As this type of laser emits infrared radiation (1.06 µm), the energy of the photons is lower than the energy of the molecular bond. They must therefore be accumulated (in the form of heat) in order to break the bonds. This leads to a thermal effect and the heat propagates through the material.

The duration of the pulse also has an effect. The thermally affected thickness is proportional to:

$$e = f(\sqrt{Kt})$$

where:

e	:	thickness of material treated
K	:	material diffusivity
t	:	irradiation time

Thus, the longer the pulse, the higher the thermally affected depth.

2.2 - Stripping with CO_2 TEA LASER (10.6 µm)

CO_2 TEA LASER stripping can also be explained by a thermal model. The advantage of this type of LASER lies in its high paint absorption coefficient at 10.6 µm (greater than 90%) and therefore a LASER-to-thermal energy conversion rate much higher than that of a YAG LASER.

2.3 - Stripping with Excimer LASER
(193, 248 or 308 mm)

Excimer LASER stripping can be explained by a photochemical model. The phenomenon involved is called «photoablation».

The radiation emitted is in the ultra-violet range (308 nm for the XeCl LASER). As the energy of a photon is greater than that of the molecular bonds, each photon emitted can in theory break one of these bonds. The material is then «vaporized» layer by layer.

3 - PARAMETERIZATION

3.1 - Travel speed

This is the travel speed of the test specimen in front of the LASER beam.

The higher the speed, the lower the time the beam remains at a given location on the test specimen. Energy density is therefore lower and stripping intensity reduced. To obtain selective stripping, stripping speed must therefore be increased.

Also, speed is directly related to the efficiency of the process.

3.2 - Pulse frequency

The number of pulses per second affects the efficiency and not the stripping quality. If the parameters are optimized, both frequency and speed can be doubled and same stripping result will be obtained without changing the other parameters.

3.3 - Energy

Proton energy $E = h\nu$, where ν is radiation frequency emitted by the LASER.

Radiation energy increases with the number of photons emitted by the active material of the LASER during firing.

The chance of breaking the molecular bonds are increased when the number of photons is increased. Thus, the higher the radiation energy, the better the stripping efficiency.

3.4 - Form of LASER spot

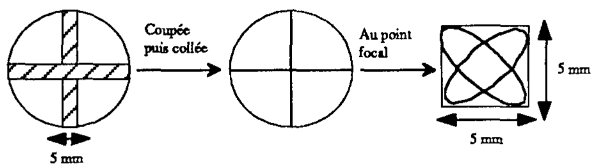
Depends on the lens used and the lens-part distance.

With the YAG LASER, the lens used had been cut into four then rebonded (see diagram).

It allows a uniform and square spot to be obtained at the focal point. A lens of this sort is used to produce a uniform spot on the specimen.

The specimen is then placed at the focal point of the lens and the lens-part distance must not vary.

Diagram :



With the Excimer LASER, the lens used was cylindrical. It allowed an energy line to be obtained.

When the lens-part distance is moved towards the lens focal distance, the beam converges to form a thin line. This distance will be selected greater than the lens focal distance to strip paint over a larger area.

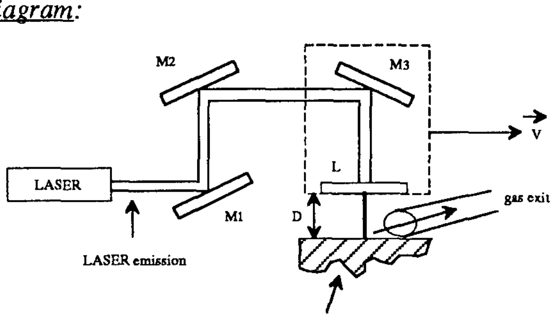
GAS :
During the tests, a blowing test was performed to increase stripping efficiency; but the effect of the blown gas was negative.

4 - USE

A LASER beam stripping installation consists of several components as follows:

- a LASER source,
- a LASER beam guide system,
- a focussing head,
- a gas and residue suction and filtering system,
- a stripping head travel system.

Diagram:



Legend :

d = stripping distance
V = travel speed
M1,M2,M3 = reflecting mirrors

This type of installation is highly automated and the commands and the information relevant to the various sensors are displayed on computer screens.
At present, only automated LASER stripping can be achieved on account of the accuracies and movements required.

5 - TESTS CONDUCTED

5.1 - Test specimens

- The metallic test specimens were made of clad 2024 aluminium alloy. They were protected by chromic anodizing and a polyurethane primer.
  The polyurethane paint system applied was of the wash primer, primer and top coat type.

- The composite test specimens were made of T300/914 monolith carbon protected by a colored primer plus a polyurethane top coat.

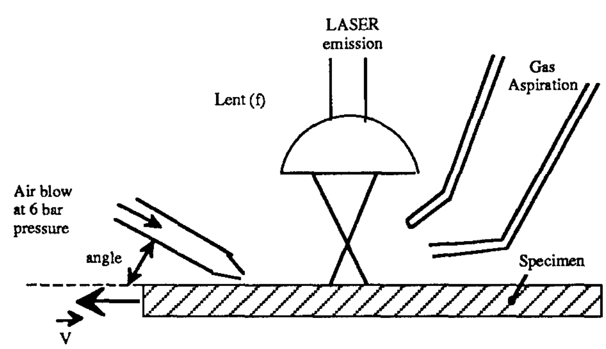
  The top coat paints were aged in hot and wet atmospheres before the tests were conducted.

5.2 - Choice of LASER

After various preliminary feasibility tests on test specimens, using YAG, CO_2 TEA and Excimer LASERs, the YAG LASER was selected on account of the results obtained.

The test configuration retained was as follows:

Diagram



Legend

V = travel speed
a = 30°
f = 150 mm (focal distance)
- available power = 1 kilowatt

5.3 - Results

- For the metallic test specimens, it was possible to show the existence of an operating point for complete stripping for which we obtained very low productivity and a very low Ra ≈ 0.3 µm.
  After the stripping operation, the surface had a residual layer of paint dust. We therefore had to clean the surface with alcohol to eliminate this coat. This operation could be avoided by improving plasma blowing during stripping.
  After stripping, the surface was homogeneous but not uniform: energy distribution was not sufficiently uniform.
  It was not possible to perform selective stripping.

- For the composite test specimens, it was possible to show the existence of an operating point for complete stripping and one for selective stripping.

  For complete stripping, productivity was very low and the surface finish value Ra obtained was 7 microns.

  The energy distribution of the LASER spot was not sufficiently homogeneous to allow complete stripping. Visual observation revealed zones where the composite was damaged.

  For selective stripping, productivity obtained was very poor and surface finish Ra was 3 microns.

  Visual observation showed that the coat of blue polyurethane primer absorbed less LASER radiation than the top coat. The primer therefore acts as a barrier protecting the substrate.

5.4 - Conclusion

LASER beam stripping can be achieved using several active materials: YAG, CO_2 TEA or Excimer.
The YAG LASER appears to be the most efficient LASER assessed. However, the results obtained, productivity, quality and type of stripping, were very poor.

Also, for stripping and on account of its specificities, the LASER beam can only be used in an automated manner.

In spite of these results, it seems that certain companies in Europe have recently developed technical solutions allowing better results to be obtained.

Mr. Olivier Malavallon
Aérospatiale
Direction des Etudes
A/DET/CG-MP
Toulouse Est. 316 route de Bayonne
31060 Toulouse Cedex 03
FRANCE

1 - REQUIREMENTS

At the end of the 80's, some of the large European airlines expressed a wish for paint systems with improved strippability on their aircraft allowing the possibility to strip down to the primer without altering it using «mild» chemical strippers based on methylene chloride.
These improvements were initially intended to reduce costs and stripping cycle times whilst facilitating rapid repainting, and this without the need to change the conventionally used industrial facilities. The level of in-service performance of these paint systems was to be the same as the previous ones. Requirements related to hygiene, safety and the environment were added to these initial requirements.

2 - DEVELOPMENT

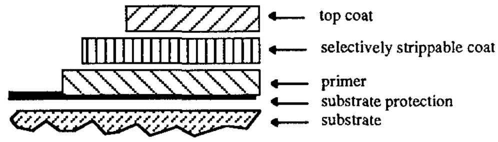
To meet customers' expectations, AEROSPATIALE, within the AIRBUS Industrie GIE, formed a work group. This group was given the task of specifying, following up the elaboration and qualifying the paint systems allowing requirements to be met, in relation with the paint suppliers and the airlines.

2.1 - Concept

The analysis made showed the interest of transferring as far upstream as possible (to paint conception level) most of the technical constraints related to stripping.

Thus, the concept retained for the paint system, allowing selective chemical stripping, is a 3-coat system with characteristics as near as possible to the previously used paints.

Diagram :



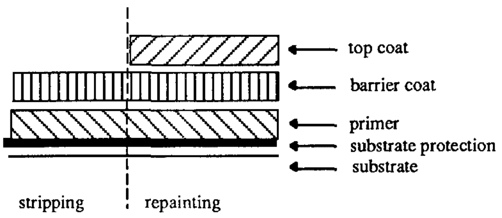
2.2 - Mechanism

The innovation of this concept lies in the integration into a paint system of a specific coat acting as a barrier against the chemical strippers used. This type of coat can have two behaviors according to its chemical nature:

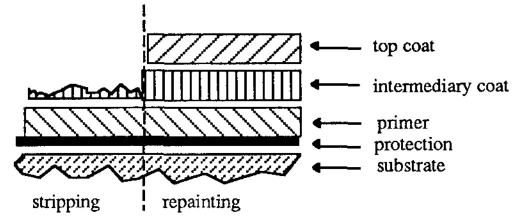
- in the first case, this coat acts as a screen for the stripper and is not altered or consumed; repainting only requires the reapplication of the top coat.

In this case, this coat is called a barrier coat.

Diagram:



- in the second case, this coat acts as a screen which is consumed by the effect of the stripper; this degradation may be partial or total. Repainting is therefore required to restore the damaged coat, by reapplication of the product, followed by application of top coat.
In this case, this coat is called the intermediate coat.



2.3 - Technical specification

A technical specification was drawn up (TN A007.10028) from the existing technical specifications for external paints and primers (TN A.007.10012 and TN A007.10113). This specification repeats the main requirements in order to guarantee same performance levels.
This specification mainly requires a flexible top coat with very good resistance to UV radiation, good intrinsic adherence of the system on protections applied on substrates (metallic and composite) of external surfaces, good fluid resistance, very good resistance to impact and bending and very good corrosion resistance behavior.

2.4 - Industrial facilities and processes

The industrial facilities used both for paint application and stripping are the same as those conventionally used.
The stripping product application methods are the same. Rigourous selection of the products to be used is required and the operators must be trained.

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

3 - WORK

3.1 - Fine-tuning

Work has been undertaken by AEROSPATIALE in close cooperation with the aeronautical paint suppliers. The test results obtained and the methods used have allowed to validate and, in certain cases, adapt the requirements specified in the AIRBUS technical specification.

This fine-tuning and validation work included, on the one hand, demonstration tests on forms representative of the aircraft and, on the other hand, very complete laboratory tests. These were completed by full scale application tests on AIRBUS A320 and AIRBUS A340 aircraft allowing the paint system to be validated for use in the workshop.

3.2 - Qualified paint systems

The first research work began in cooperation with the French company MAP Aero with technical and financial backing from STPA. It allowed us to qualify, at the start of the 90"s, the following scheme:

- anti-corrosion primer: ISOMAP P23
- barrier coat: MAPSTRIP S15
- flexible UVR top coat: AEROMAP 1000

Following this, the international group COURTAULDS Aerospace and its French subsidiary International Celomer qualified the following scheme at the beginning of 1994:

- anti-corrosion primer: INTERGARD 90
- barrier coat: CA 30.000
- flexible UVR top coat: CA 40.000

A third paint system for selective chemical stripping was developed by the AKZO-DEXTER Aerospace Finishes group but for which the qualification work could not be started.

3.3 - Chemical strippers

Development and fine-tuning work on products containing no chromates or phenol and, if possible, no methyl chlorides, has been started by certain manufacturers. The first results show that the efficiency of these products depends in part on repainting times, type of coat (barrier or intermediate) and chemistries used to elaborate them. However, encouraging results have been obtained.

4 - EXPERIENCE ACQUIRED

4.1 - Industrial application

Application tests on aircraft have allowed the working methods used to be adapted to suit and the operating method, the parameters used and the associated documents to be validated.

Correlations between laboratory tests and workshop applications have highlighted the importance of the parameters related to the operating method, such as repainting times. Their effects have been quantified and taken into account in the industrial process to guarantee the quality and reliability of the paint systems whilst taking industrial requirements into account.

4.2 - In-service fleet

At present, the in-service aircraft fleet used by AIRBUS Industrie's customer airlines consists of around twenty aircraft including AIRBUS A320s, AIRBUS A330s and AIRBUS A340s.

Their in-service behavior and the associated maintenance operations are subject to regular follow-up between a group of AIRBUS Industrie partner specialists and the user airlines.

5 - FUTURE OUTLOOKS

5.1 - Painting policy

AIRBUS Industrie and its partners have elaborated a painting policy allowing the customers' requirements to be met as far as possible. These requirements vary significantly according to the size of the airlines and the economical and technical constraints to which they are submitted. Several alternatives therefore had to be offered.

Among these technical alternatives, the selectively strippable paint systems, offered with all guarantees, allow the use of stripping products which have very limited effects on the environment and guaranteeing efficient and economically viable industrial cycles.

5.2 - Technical developments

The technical improvements to be made to the selective chemical stripping paint systems mainly concern the new environmental and hygiene - safety requirements. The aim of these developments is to limit the investments required to achieve conformity with new legislation.

The possible improvements are:

- low VOC technologies and chemistries,
- stripping products free from substances harmful or highly polluting for the environment and which do not lead to extra costs for processing waste.

It is also possible that certain improvements or adaptations can be recommended subsequent to in-service use.

5.3 - Change in demands

The possibility of stripping down to the primer (external paint system), without altering it, with «mild» strippers without chromates or phenols and, possibly, based on methylene chloride, corresponds to the requirements made by certain airlines in the early 90's.

These requirements are very closely related to the operational requirements and environmental constraints. Their changes will dictate the future outlooks for this concept which specifically associates the paint system and the stripping process.

FACILITIES USED FOR PLASTIC MEDIA BLASTING

Dr. Terry Foster
Esquimalt Defence Research Detachment
FMO Victoria
Victoria, B.C., Canada V0S 1B0

1. INTRODUCTION

The equipment used for plastic media blasting (PMB) is generally independent of the media and is similar to equipment used in traditional abrasive blasting. PMB equipment is usually modified to enable the close control of the media flow and the operation at low pressures (30-40 psi). Because of the delicate nature of some of the stripping procedures, the nozzles used for PMB have been redesigned to improve cleaning rates, give an even distribution of particles and reduce the variation in particle velocity across the blast stream. This results in a more equal distribution of particles and impact energies at the substrate.

There are three types of blast facilities available:

- Blast Cabinets for small components
- Blast Booths which will accommodate larger components but may be used for purposes other than blasting, and
- Blast Rooms which are designed for complete vehicles or aircraft and are generally not used for other purposes

Some components are common to all three types of facilities and only vary in scale depending on the size of the facility. A blast facility for PMB will usually include the following components:

- air compressor
- pressurized feed hopper for media
- media flow control valve
- blast nozzle
- recovery system for spent media
- magnetic separator to remove magnetic particles
- recycling system to clean media and remove dense particles, and
- hoses to transport the media

The volume of the air supply will depend on the size of the facility, number and size of blast nozzles and the recovery and recycling system used. All blast facilities require dry compressed air to avoid clumping of the media and to ensure an even flow of media during the blasting process.

2. BLAST CABINETS

A small blast cabinet for PMB is listed and identified by a US National Stock Number NSN 4940-01-225-3845. This type of cabinet is available from many suppliers of plastic media and these suppliers should be consulted prior to purchase of a PMB Cabinet.

Blast cabinets generally use 1/8" or 3/16" blast nozzles and require up to 100 ft^3/min of air per nozzle to operate at pressures up to 40 psi. Cabinet manufacturers should be consulted as to air requirements prior to purchase of a blast cabinet.

A typical blast cabinet has a working area of 5 feet by 4 feet. Although this area limits the size of components that will fit in a blast cabinet, the standoff distance (usually 12-18 inches) from the component should also be taken into consideration in the choosing size of blast cabinet.

Some problems associated with blasting components in a cabinet include the following:

- working volume and the need to control the blast angle and standoff distance can restrict the size and complexity of the component to be stripped
- due to the confinement of the media, visibility for complex operations can be difficult at times
- flexibility and manipulation can be restricted due to the use of rubber gloves which restrict reach, sense of touch and movement.

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

3. BLAST BOOTHS

Blast booths offer the flexibility of size and allow access to all sides during blasting of large structures and components. The actual configuration of a blast room will vary from site to site and depend on the space available and the equipment to be stripped.

The booth can either be a temporary enclosure made of plastic sheeting in a larger area or a metal enclosure placed in a hanger or other work space.

Most of the blasting equipment used in a blast booth is similar to that used in a blast cabinet except scaled to suit the size of the booth and the number of blast nozzles in operation. Ventilation of the blast booth area and an air supply for the blast personnel will place an extra load on the air supply system and could require a separate air system. The most significant component of a blast booth is the media recovery system. A floor recovery system will automate the recovery and recycling of the media and prevent build up of spent media in the booth. A manual vacuum recovery system can also be employed to remove the spent media from the floor of the booth. A manual vacuum system may require blasting to stop while the used media is recovered.

It is also recommended that a dense particle separator (DPS) be an integral part of a blast booth. The DPS removes any heavy particles from the recycled media such as pieces of metal, fasteners, sand, and other non-ferrous particles. These particles may have been brought into the booth by blasting personnel or be dislodged from components during blasting. If dense particles are not removed, damage to blasted surfaces may occur.

4. BLAST ROOMS AND AUTOMATED BLAST SYSTEMS

A blast room is designed to accommodate a complete aircraft and is dedicated as a blasting facility. Its size will be determined by the maximum size of aircraft expected to use the facility.
A blast room requires the following components:

- adequate ventilation to meet local health standards for personnel exposure and to maintain dust levels below that for combustion or explosion
- fire suppression system to protect the personnel, the aircraft, and the facility
- plastic media blast system with sufficient blast nozzles and blast pots and media storage capability to meet the desired level of productivity
- classification and cleaning system (cyclone air washes, vibratory screens, dense particle separators, and magnetic separators) capable of processing the volume of media required to maintain continuous operation
- recovery system to automatically remove the media from the floor of the blast room
- crane or scaffolding system to allow operators access to all parts of the aircraft
- an additional feature may be a robotically controlled blasting system

To install and operate a blast room input from all personnel involved in the process is required along with consultation with the manufacturer of the media and blasting equipment (turnkey systems are available from some manufacturers).

5. PMB EQUIPMENT

5.1 Media Delivery Systems

All three types of blasting facility require a media delivery system consisting of the following components:

- pressurized blast pot
- media flow control valve
- media storage vessel
- safety control devices
- blast nozzles and hoses

The media flow in a blast cabinet can be controlled with either a microprocessor controlled flow valve or the valve on the feed hopper (pinch valve) is calibrated.

After the media has passed through the recovery system, it then flows to a media storage hopper directly above the pressure vessel. When blasting is stopped for any reason, the media in the storage hopper flows into the pressure vessel for use. Depending on the media flow rate, the pressure pots should contain up to a thirty (30)

minute supply of blast media. This can vary with each manufacturer's design.

As a safety precaution all of the pressurized systems have pressure relief valves that are activated in case of a blockage of media flow that could cause a pressure buildup. As a safety precaution, most operating systems have a release switch ("deadman") at the nozzle that, when released, causes the system to stop and depressurize .

Proper selection of blast hoses and couplings is important from at least two points of view. Air leaks need to be minimized with good fittings to ensure efficient operation of the system. Proper hose selection will ensure proper media flow and eliminate media contamination due to hose breakdown. Manufacturers recommendations should be followed in the selection of hoses and couplings.

Blast nozzle designs are generally proprietary but include a regular venturi nozzle used for many years in traditional sand blasting operations, a double venturi nozzle designed for increased blasting efficiency and a new "flat" nozzle for use with newer, softer media that gives a better impact profile on the blast surface.

5.2 Media Recovery Systems

In a blast cabinet the media falls to the bottom of the cabinet and is vacuumed into the media reclamation system. In a blast booth the media can either be vacuum recovered from the floor of the booth or an automated recovery system can remove the media from a floor grid system similar to that in a blast room.

In the reclamation process the fine or dust particles are removed in a dust collector and the remaining media and contaminants are transported into a cyclonic chamber. In the cyclonic chamber the heavy re-usable media is thrown to the outer walls where it spirals down through an air wash which removes any remaining debris from the reusable media. The media then passes over a vibrating hopper to remove any oversize particles and correctly size the reusable media. The reusable media then passes over a magnetic detector to remove any magnetic debris and subsequently flows into a storage hopper above the pressure vessel. Whenever the blasting process stops, the media from the storage hopper is automatically transferred to the pressure vessel.

As the media breaks down it must be replaced. Hence regular additions to compensate for media breakdown must be scheduled into the blast process. Similarly as the media is used a number of times it will no longer have the cleaning efficiency of new media and it should then be replaced. The rate at which the media breaks down will depend on the types of coatings removed, the hardness of the substrates and the age and difficulty of removing certain coatings. When cleaning efficiency drops significantly the media should be replaced.

5.3 Dense Particle Separators

In blast booths and rooms a heavy particle separator should be employed. Experience has shown that dense particle contamination can occur in these type of blast facilities. Dense particles can include any or all of the following:

- sand, glass and other silicate materials
- non-ferrous (aluminum, magnesium and zinc) and ferrous metal particles
- high density plastics.

If these particles are not removed from the blast stream, damage can occur to blasted components.

There are three types of heavy particle separation technique:

- fluidized bed
- air wash system
- inclined vibrating deck

The fluidized bed system is the most popular and most readily available DPS. Manufacturers should be consulted as to which type of dense particle separator is available with their equipment. No matter which DPS is chosen, its efficiency should be routinely checked using the Boeing test method (Boeing D6-54707 Heavy Particle Contaminants Test Method). A level of less than 200 ppm measured using this test method is the

accepted level of both the US and Canadian military and Boeing. In this method, several samples of the recycled blasted media are weighed and placed in containers of a solvent more dense than the blast media (usually a Freon). The plastic media will float on the surface of the solvent and the dense particles will fall to the bottom of the container and can be weighed and examined.

The air wash cleaning system is usually an off-line system but may be configured to operate as part of a continuos PMB system.

The air wash system consists of the following six steps some of which may be combined:

- a vibrating screen (0.125 inch mesh) is used to remove the gross contaminants
- a cyclone separator is used to remove fine paint particles and dust
- a large powerful magnet is used to remove any ferrous contaminants
- a multiple stage vibrating screen is used to sort and classify the media by mesh size
- after classification into three or four preselected mesh sizes, the media then falls through an air channel, where it is subjected to an air separation process to remove any dense particles
- the cleaned plastic media is then recombined and mixed by the air stream and returned to the storage hopper.

Air wash systems using screens of thirty inches in diameter are capable of processing up to 1,000 lbs per hour of plastic media.

The inclined vibrating deck system was developed by the grain industry to separate similar sized grains that differ in density. This type of system has been evaluated at several USAF bases but is not in general use in the PMB industry.

6. CONCLUSIONS

There are three types of PMB facilities available; blast cabinets, blast booths and blast rooms. Individual requirements will be the leading factor in choosing the type and size of facility required.

TREATMENT OF PLASTIC MEDIA WASTE

Dr. Terry Foster
Esquimalt Defence Research Detachment
FMO Victoria
Victoria, B.C., Canada V0S 1B0

Although plastic media itself is not generally considered a hazardous waste, the paint particles containing chromate pigments contaminating the spent media are considered a hazardous waste product. There are currently four approaches under investigation aiming to reduce the volume of hazardous waste produced during paint stripping:

- elimination of the chromate containing pigments or other hazardous pigments from primers and coatings
- separation of the paint or hazardous materials from the plastic or other media
- encapsulation or recycling of the contaminated media to make it safe for disposal or reuse
- produce a biodegradable media.

Research to develop new pigments and primers that will result in the elimination of hazardous pigments such as strontium chromate and into developing alternative anti-corrosive surface treatments to replace cadmium plating is continuing. Contamination of the spent media will remain a problem because the hazardous pigments and surface treatments will still be used on aircraft and their components for the foreseeable future. Therefore, the only realistic alternatives at the moment to reduce the volume of hazardous waste produced by PMB are to re-cycle or re-use the media in some form or remove the hazardous materials from the media.

Complete separation of the paint particles from the plastic media is difficult and time consuming and is not currently an economic approach to solving the problem of hazardous waste. The dust and fines recovery process of plastic media blasting does remove some of hazardous waste particles and therefore, this dust must be treated as a hazardous waste products.

The US Technologies Corp.[1] has developed a recycling technique to recycle spent media and paint residue. The technology utilizes the media and paint residue as an ingredient in the manufacture of plumbing fixtures such as sinks, showers and vanities. This encapsulates the hazardous waste in a non-leachable form which is acceptable under environmental regulations. This is a proprietary process which is awaiting patent approval. This process has received the required approvals from the US Environmental Protection Agency (US EPA) and various local agencies as an approved recycling process for plastic media.

More recently a method of recycling Type V (acrylic) plastic media has been developed jointly by Sacramento Air Logistics Center (SM-ALC) and Battelle.[2] A pilot project has been initiated to convert spent acrylic media into pellets that can be re-ground into blasting media. As any hazardous materials in the spent blast media are encapsulated during this process, the pellets meet the leaching rate standard of the US EPA. The recycled media has been shown to have similar stripping rates, aggressiveness and breakdown rates as new media. A full scale prototype is under development and should be operational by 1995.

A final and more attractive method to reduce both the volume of hazardous waste and the need for recycling is to formulate a biodegradable media. One alternative media which will be discussed at some length during this lecture series is wheat starch. As wheat starch is a natural product it is completely biodegradable and an enzymatic biodegradation process has been developed for this media. A second media currently under development is based on modified corn starch. Research on this media is still at the preliminary stages but some progress has been made.[3]

References

1. R.F. Williams, "PMB - Hazardous Waste Alternatives", paper presented at the 1994 DoD/Industry Advanced Coatings Removal Conference, New Orleans, USA, May 1994.

2. A.O. Rockswold, S.K. Mayer, H.N. Conkle and D.M. Bigg, "Repelletization of Spent Type V Plastic Blasting Media", paper presented at the 1994 DoD/Industry Advanced Coatings Removal Conference, New Orleans, USA, May 1994.

3. R. Kovar, K. Blizard and L. Rubin, "Biodegradable Plastic Media Blast Materials", paper presented at the 1994 DoD/Industry Advanced Coatings Removal Conference, New Orleans, USA, May 1994.

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

Bioremediation of Wheat Starch Media Waste

Mr. Olivier Malavallon
Aérospatiale
Direction des Etudes
A/DET/CG-MP
Toulouse Est. 316 route de Bayonne
31060 Toulouse Cedex 03
FRANCE

Mr. John Oestreich
Soc. C.A.E. Electronics Ltd.
Montreal, Quebec
Canada

1 - REMINDS

The development of a bioremediation process is designed to minimize most of the waste generated with dry media paint removal. The bioremediation method was developed by DOT Technologies in Canada.

When paint is removed with wheat Starch Media, a dust waste is produced containing both starch and paint. The waste will also contain a percentage of inorganic materials from the starch, the paint waste and contaminants from the aircraft (sealants, tapes, ...).

2 - PRINCIPLE

This disposal method first uses enzymes to render the starch component soluble in water, converting the starch to various sugars. Specially bred bacteria then digest the sugars, and some of the hydrocarbons in the paint. At this stage, the primary end products are carbon dioxide and water. This bioremediation method reduces the waste generated by dry paint removal by approximately 95%.

The bacteria, bred by natural selection, tolerates high levels of heavy metals, and toxic hydrocarbons.

The basic chemistry of bioremediation, as well as the management of bacteria in this application are summarized hereafter.

3 - TRIALS

The process is based on research performed on a semi-commercial size pilot unit. This unit, operated by DOT Technologies, processes up to 70 kg per batch, and digests the starch waste at a rate of over five kg of waste per hour.

More than one tonne of waste has been processed in prototype trials. Waste starch media has been supplied by various North American companies including BOEING, NORTHROP GRUMMAN, BEECH AIRCRAFT, CANADIAN HELICOPTERS and the CAE Test Center. The source of the waste, type of paint removed, and mesh size of the waste had no discernible effect on the bioremediation process.

4 - PROCESSING

The following operational sequence is used either for the pilot unit operation or for a 100 MT/year facility.

- Step 1 : The starch waste must first be liquified. The starch waste is automatically dispersed into pre-heated water (96 - 98°C). The starch will be fully hydrated at this temperature. A heat stable alpha-amylase enzyme then breaks down the starch, solubilizing the starch polymers. The enzymes require 60 minutes to completely liquify the starch waste. Then the waste is cooled to 30 - 33°C and afterwards transferred to the bio-reactor.

- Step 2 : The starch waste is continuously circulated from the bio-storage vessel, through an air tower, to the bio-chamber, and then returned to the bio-storage tank. Bacteria and nutrients are added to the bio-reactor and the waste is then allowed to digested for several days. During digestion, the temperature of the waste is maintained at 30 - 33°C, air is supplied via the air tower, and the pH is monitored and adjusted to a neutral level.

- Step 3 : As the digestion of the starch sugars proceeds, the sugar level decreases. To maintain optimum bacterial action, a quantity of liquid waste is automatically transferred from the biostorage unit to the evaporator. In the evaporator, the volume of waste is reduced by 50%. The concentrated waste is then returned to the bio-chamber. A newly dispersed volume of waste, equal to the volume of water lost through evaporation, is automatically added to the bio-chamber to maintain a constant waste volume level.

- Step 4 : Once digestion of several batches has been completed over a period of several weeks, the residual waste is collected in the evaporation unit. This is concentrated into a paint sludge and is removed from the system. In this way, the inorganic materials are removed.

- Step 5 : The water produced during digestion evaporates and is vented to the atmosphere through an activated carbon filter. The water evaporated during concentration of the waste can be recovered and reused, minimizing any effluent to the environment.

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

5 - MONITORING

In order to ensure a good functionment and the follow up of the bio-remédiation system, tests are performed. For example, if the sugar levels increase as indicated by a specific gravity reading, the bacteria may have become inactive during the digestion cycle. The waste solution pH, temperature, and air supply should be verified and corrected if necessary. If all equipment is operational, a new bacteria and a nutrient package are added to restart and to insure the digestion cycle.

6 - ECONOMICS AND CONCLUSION

Today's commonly used methods are primarily land-fill and incineration. It appears after analysis that the bio remediation costs are in France at the same level of cost than for land-fill or incineration. Since the costs of these methods are expected to rise in the future, bioremediation offers an efficient alternative method of protecting the environment, and controlling disposal costs over the long-term.

OPERATIONAL PARAMETERS AND MATERIAL EFFECTS

Dr. Terry Foster
Esquimalt Defence Research Detachment
FMO Victoria
Victoria, B.C., Canada V0S 1B0

1. INTRODUCTION

Although there are six types of plastic media, the focus on operational parameters and materials effects of PMB will be on the Type V acrylic media with some reference and comparisons to Type II media. The other four plastic media are not used extensively in general aircraft stripping and will not be discussed in this paper. There are several military and commercial documents available with detailed procedures for plastic media stripping of aircraft and some of these are shown in Table 1. The actual choice of blasting parameters will to a great extent depend on the media chosen and the substrate to be stripped.

Country	**Document Title**
USA	Technical Order 1-1-8 Application of Organic Coatings, Aerospace Equipment, Sections 2-7 and 2-14
Canada	
McDonnel Douglas	CSD #4 Oct 19 1988
Airbus	SIL 51-007 Sept 6 1989 and AIPS 02-100 Jan 30 1990

The effects of various blasting conditions on materials can be evaluated using visual, optical microscopy, scanning electron microscopy (SEM) and mechanical and corrosion test methods. The American Society for Testing and Materials (ASTM) test methods, relevant to PMB, for metals and composites are listed in Table 2. In some test methods up to twelve specimens are required to give meaningful results, therefore statistical analysis tools are also required to interpret the results due to the scatter in some of the data.

2. SURFACE EFFECTS OF PMB

The impact of plastic media particles on a substrate surface can effect the surface in two ways: I) the peening effect of the particles can induce residual surfaces stresses (peening), and ii) the surface can be roughened or eroded.

Roughening of the surface during plastic media blasting is most notable with alclad alloys. As the clad layer is much softer than the underlying aluminum substrate the impinging media will smear and roughen the alclad surface. This effect is also dependant on the angle of impingement of the blast particle. An example of surface erosion is the removal of the anodizing layer on the surface of aluminum alloys.

The surface of composite materials can also be damaged during PMB. Broken or exposed fibres are usually the most obvious indication that PMB has damaged the composite surface.

The effect of induced compressive stresses on the surface of aluminum alloys is distortion and warpage of the structure or test specimen and in some cases a loss of mechanical properties. This warpage is measured as the Almen Arc height using the test described later. High Almen arc heights indicate that a high residual surface stress has been produced. Increased surfaces stresses are unacceptable on aircraft structures and is one of the reasons why PMB is not used on all aircraft materials. The Almen arc height is also used as a method of determining the acceptable blasting conditions for the various types of media.

3. MECHANICAL PROPERTIES OF METALS AND COMPOSITES

Fatigue of metals is a major concern in aircraft structural integrity and as PMB can effect the surface properties of a metal (e.g. increased roughness and residual stress) increased fatigue crack growth rates have been a concern. There has been no evidence to date of reduced

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

fatigue life as a result of PMB for aluminum alloys of greater than 0.06 inches thickness.

In alloys of less than 0.06 inches thickness fatigue can be reduced by as much as 66% (0.032 inch, notched Al 2024-T3). In general, fatigue crack growth rates are affected by the following blast parameters and materials properties:

- increasing blasting pressure
- increased dwell time or number of blasting cycles
- reduced specimen thickness
- presence of dense particle contaminants in the media
- the type of aluminum alloy, with Al 2024-T3 showing a greater increase in fatigue crack growth rate than Al 7075-T6.

To reduce the effects of PMB on fatigue crack growth rates blasting parameters must be chosen that reduce the level of induced surface stresses or peening.

For composite surfaces, erosion or damage to the surface can lead to degradation of mechanical properties (tensile, flexure, fatigue life and compression). The blasting parameters used on composite surfaces are generally less severe than those chosen for metal surfaces. The factors that can result in surface damage to composites include:

- long dwell times or repeated stripping of a surface
- choice of media, generally media with a hardness of 3.5 Moh (Type II) are more damaging than media with a hardness of 3.0 Moh (Type V, acrylic)
- blast angle, the more shallow the blast angle the greater the chance of surface damage
- lower blast pressures and increased standoff distances reduce the possibility of surface damage but also result in slower stripping rates, these two factors must be balanced in choosing blast parameters
- removing only the topcoat of a coating system and leaving the primer intact will also result in reduced surface damage

The easiest and most direct method of determining surface damage on composite is by optical microscopy or SEM. Inspection of the surface for broken fibres, cracks in the resin, lack of surface resin or missing fibre layers are indications that damage has occurred. Interlaminar or subsurface damage must be detected using non-destructive means such as x-ray or ultra-sound or microscopic examination of cross-sections.

Unless harsh blasting parameters are used (high pressures and close stand-off distances) that result in visible fibre damage or matrix cracking, there has been no observed degradation in the mechanical properties (tensile, flexural, compressive, interlaminar shear strength, or fatigue properties) of fibre composites from PMB.

4. ALMEN ARC HEIGHTS AND BLASTING PARAMETERS

In the Almen Arc Test a strip, 3" x 0.75" x 0.032", of 2024-T3 aluminum (or other alloy as required) is securely fastened to a steel plate with four fasteners as shown in Figure 1. The aluminum strip is then blasted for various periods of time (usually 2.5, 5, 10, 20, 30, 40, 50 or more seconds). The Almen strip is removed from the holder and the warpage or arc height is measured after each blast time. The Almen Arc height is then plotted as a function of blast time as shown in Figure 2. Saturation has occurred when a doubling of the blast time results in a change in arc height of less than 10% . Once saturation occurs no further blasting is required.

The Almen arc test is useful in obtaining the best combination blast parameters for each media, (pressure, standoff, blast angle, and media flow rate) that result in the least residual stress while maintaining an acceptable coating removal rate. In many blasting specifications a maximum Almen arc height for a given number of blast cycles is specified, usually 0.006 inch (0.15mm) using inch Al 2024 (0.032 inch thick). This means that for the any given blast parameters and media, the Almen arc height must be less than that specified after blasting for the set number of blast cycles.

Two examples of the effects of various blast parameters on the Almen arc height are shown in Figures 2 and 3.

From Figure 2 it can be seen that both blast angle and media flow rate can effect the Almen arc height. Higher flow rates, more media impacts per second, and a 90° blast angle, more efficient transfer of energy to the substrate surface, both result in increased Almen arc heights.

The effect of the hardness of the various media types can be seen in Figure 2. The harder more dense media, Type II (3.5 Moh, 1.5 gm/cm^2), gives significantly higher Almen arc heights than the less dense media, Type V (1.2 gm/cm^2), or the softer media, wheat starch (3.0 Moh).

Standoff distance will also obviously have an effect on the Almen arc height as shown in Figure 3 for a magnesium alloy at standoff distances of 12 and 18 inches, similar effects are seen for Al 2024-T3.

5. CONCLUSIONS

When used with attention to the choice of blast parameters and with an understanding of the possible effects on material properties, plastic media blasting is a safe and effective method for removing coatings from aircraft structures. The effects of PMB on materials have been well documented over the last several years and are well documented (see bibliography).

The Almen arc height test is also a useful test for determining the effects of various combinations of blast parameters on materials. It can also be used as a qualifying procedure whenever a new PMB process is to be qualified.

There are several specifications (military and commercial) available to the new user of PMB. This will enable the user to reduce the time required to get a PMB facility operational and help provide a thorough background knowledge of PMB.

TABLE 2 - TEST METHODS FOR EVALUATION EFFECTS OF PMB ON MATERIALS

Test Method	Title
Metals	
ASTM E206	Fatigue Testing and Statistical Analysis of Fatigue Data
ASTM E647	Measurement of Fatigue crack Growth Rates
ASTM E466	Conducting Constant Amplitude Axial Fatigue Tests of Metallic Materials
Composites	
ASTM D790	Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials (Method II: Four Point Flexure)
ASTM D2344	Apparent Interlaminar Shear Strength of Parallel Fibre Composites by Short Beam Method
ASTM D3039	Tensile Properties of Fibre Resin Composites
ASTM D3410	Standard Test Method for Compressive Properties of Uni-Directional or Crossply Fibre-Resin Composites
Corrosion	
ASTM B117	Salt Fog Testing
ASTM G31	Laboratory Immersion Corrosion testing of Metals
ASTM G34	Standard Test Method for Exfoliation Corrosion Susceptibility in 2XXX and 7XXX Series Aluminum Alloys
ASTM G46	Standard Recommended Practice for Examination and Evaluation of Pitting Corrosion

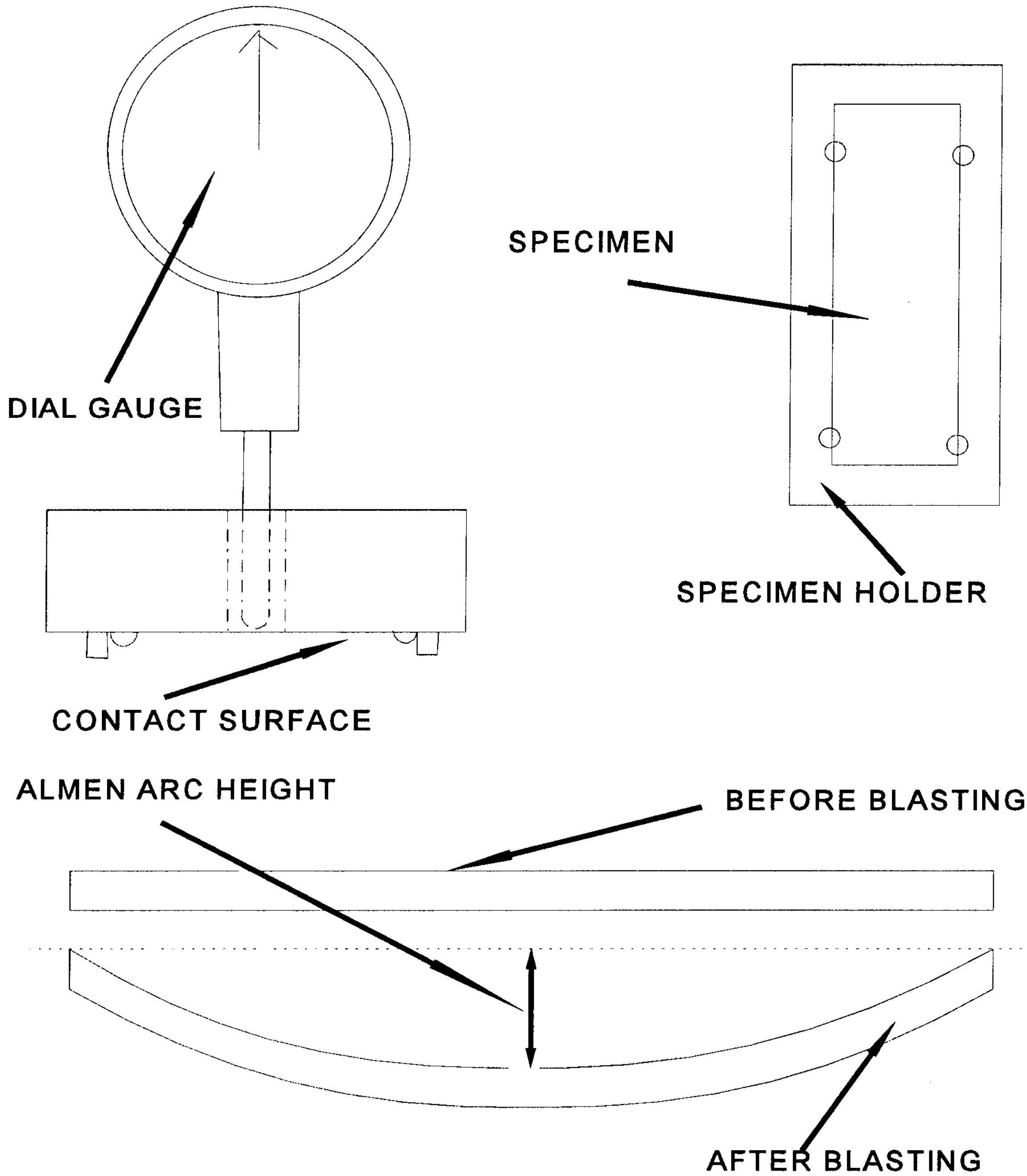


Figure 1 Almen Test Gauge and test specimen.

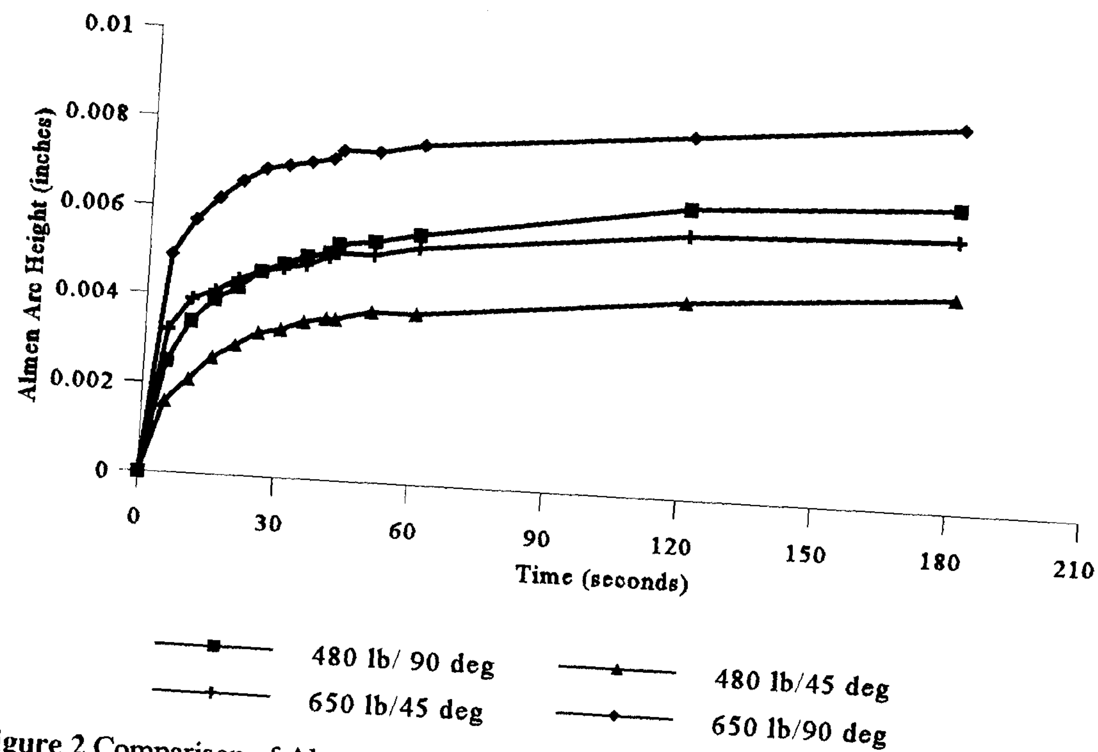


Figure 2 Comparison of Almen arc data for Type V media at two blast angles and media flow rates using a 12" standoff distance (AL 2024-T3).

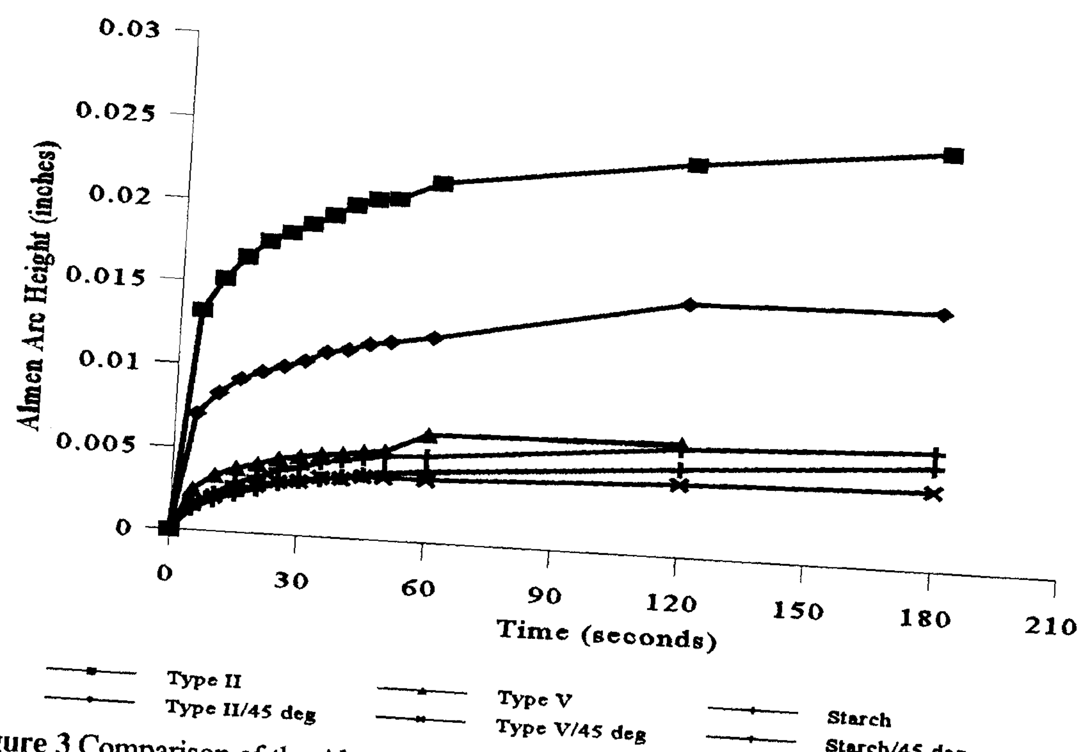


Figure 3 Comparison of the Almen arc data for Type II, Type V and Wheat Starch media at 45° and 90° at a media flow rate of 480 lb/hr and 12" standoff distance (Al 2024-T3).

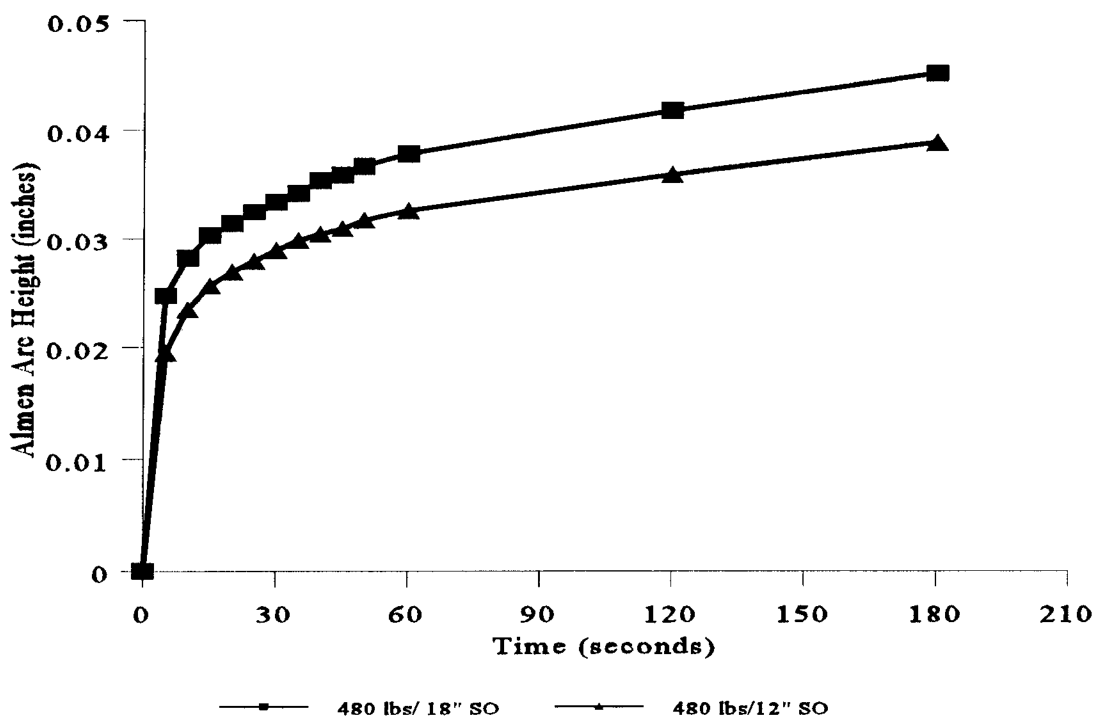


Figure 4 Comparison of the effects of standoff distance on the Almen arc data for Type V on magnesium alloy at 90 deg and 30 psi.

Process Evaluation

Mr. Olivier Malavallon
Aérospatiale
Direction des Etudes
A/DET/CG-MP
Toulouse Est. 316 route de Bayonne
31060 Toulouse Cedex 03
FRANCE

1 - CURRENT SITUATION

It is not always easy to conduct a study and implement a systematic policy in the aeronautical paint stripping field. The situations to be studied are complicated by extensive technical data, material conditions and financial unknowns. To these are added demands both in the civil and military fields to increase the performance obtained, optimize cycles, reduce recurrent costs, quickly amortize investments and now increasing respect for the environment.

To reply correctly, the various possibilities must be assessed using, if possible, identical criteria and reference systems.

The only criteria which apply to all the processes and methods is the overall stripping cost. It is not sufficient for a process to meet the related technical requirements (for example «IATA guidelines»), it must also be economically justifiable. The overall costs take into account therefore the costs and materials, labor and also the downtime of the aircraft, amortization and maintenance of the installations and processing of waste, etc..

2 - AEROSPATIALE EVALUATION

For many years now, AEROSPATIALE has undertaken research and development programs to find and evaluate alternatives to the conventional chemical stripping process. This work has led it to carry out comparative analyses from technical elements enhanced as the work progressed.

2.1 - Substrates

The substrates taken into account in the evaluations are those used on the external surfaces of civil transport aircraft. They can be divided into two families:

- metallic materials, mainly consisting of clad and unclad aluminium alloys,

- composite materials, made up of different types of structures (sandwich, monolithic) using different types of fibers (glass, kevlar carbon) and epoxy resins (120°C and 180°C).

These substrates are very often protected with different types of surface treatments (such as anodizing) or protective materials (such as bronze mesh).

2.2 - Paints

The paints applied to the surfaces of these protective substrates are conventional external paint systems. The paint system retained is the one the most often used.

This is the CELOMER International paint system (COURTAULDS Aerospace group), qualified to specification TN A.007.10013. This paint system is as follows:

- Wash primer (P99) + primer (PAC 33) + top coat (PU66).

These are flexible polyurethane paints.

2.3 - Processes

The processes selected are those which are liable to strip the paint systems applied to the external surfaces of transport aircraft.

These processes are as follows:

- solvent-based, non-phenolic, slightly chlorinated strippers (associated with the barrier coat system),
- activated acid strippers,
- PMB + type II media,
- DMB + starch media,
- water ice pellet blasting,
- CO_2 ice pellet blasting,
- Xenon lamp + CO_2 ice pellet blasting,
- very high-pressure water jet,
- high-pressure water jet,
- chemical stripping + high-pressure water jet,
- LASER,
- Xenon lamp.

2.4 - Evaluation criteria

The evaluation criteria selected take into account requirements from different fields. They can be grouped into the following categories:

- Hygiene & Safety, Environment:
  . hygiene and safety protections and requirements,
  . volume of hazardous waste.

- Technical aspects:
  . media intrusion,
  . potential corrosion,
  . potential damage on metallic substrates,
  . potential damage on composite substrates,
  . potential damage to adjacent parts,
  . ability for selective stripping,
  . reliability.

- Industrial aspects:
  . masking and precleaning,
  . final cleaning,
  . productivity,
  . cycle time.

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

PROCESSES / CHARACTERISTICS	Solvent Based Strippers	Acid Based Strippers	PMB + Type II	DMB + Wheat Starch	Ice Pellet Blasting	CO_2 Pellet Blasting	Xenon Flash Lamp + CO_2 Pellet Blasting	Ultra High Pressure Water Jet (32000psi)	High Pressure Water Jet	Softeners + High Pressure Water Jet	LASER	Xenon Flash Lamp
Masking/Precleaning Requirements	YES 10	YES 10	YES 5	YES 5	YES 5	MINIMAL 1	MINIMAL 1	YES 7	YES 7	YES 7	MINIMAL 2	MINIMAL 2
Potential Damage on Metallic Substrates	LOW 1	YES 8	LOW 1	LOW 1	LOW 1	LOW 1	LOW 2	YES 9	MODERATE 5	MODERATE 5	MODERATE 3	MODERATE 8
Potential Damage on CompositeSubstrates	YES 7	YES 10	MODERATE 3	MODERATE 3	MODERATE 3	MODERATE 3	YES 10	YES 10	YES 7	YES 7	YES 9	YES 10
Potential Adjacent Damage	YES 5	HIGH 8	LOW 3	LOW 3	YES 5	LOW 3	HIGH 7	HIGH 8	YES 7	YES 8	MODERATE 5	HIGH 8
Media Intrusion	HIGH 7	HIGH 8	YES 5	HIGH 7	HIGH 7	LOW 1	LOW 3	HIGH 8	YES 5	YES 5	NO 0	NO 0
Corrosion Potential	YES 5	HIGH 8	NO 0	NO 0	YES 5	NO 0	NO 0	YES 5	YES 5	YES 6	LOW 1	NO 0
Post Stripping Clean Up	YES 5	YES 8	YES 5	YES 5	YES 3	NO 3	NO 0	YES 3	YES 3	YES 5	YES 3	YES 5
Stripping Rate	MODERATE 4	HIGH 2	MODERATE 5	HIGH 3	NONE 10	NONE 10	MODERATE 5	MODERATE 5	VERY LOW 10	MODERATE 5	MODERATE 5	LOW 8
Reliability	MODERATE 4	LOW 9	HIGH 1	HIGH 1	MODERATE 7	MODERATE 7	HIGH 1	MODERATE 7	LOW 7	MODERATE 7	MODERATE 7	LOW 8
Health & Safety Protections	Eye, Chemical Protection 6	Eye, chemical Protection 10	(Breathing) Eye 3	(Breathing) Eye 3	Eye 1	Blast, Ear, Eye, Breathing Gas mask 5	Breathing, Ear, Eye. 8	Ear, Blast Pressure 7	Ear 1	Ear, chemical protection 4	Eye, Energy Level 7	Breaking, Ear, Eye 5
Hazardous Waste Volume	HIGH 7	HIGH 10	MODERATE 5	MODERATE 5	LOW 1	LOW 1	LOW 1	LOW 1	LOW 1	MODERATE 7	LOW 1	LOW 1
Cycle Duration	MEDIUM 4	SHORT 3	MEDIUM 7	MEDIUM 5	LONG 9	LONG 9	LONG 8	MEDIUM 5	LONG 9	MEDIUM 5	MEDIUM 7	LONG 9
Development Costs	NONE 0	FEW 1	MODERATE 5	LOW 3	HIGH 10	HIGH 10	HIGH 10	MODERATE 7	MODERATE 7	MODERATE 7	HIGH 10	HIGH 10
Investment Costs	LOW 1	LOW 1	MODERATE 5	MODERATE 5	HIGH 7	HIGH 7	HIGH 10	HIGH 10	HIGH 10	HIGH 10	HIGH 10	HIGH 8
Operating Costs	LOW 3	LOW 3	MODERATE 5	MODERATE 5	MODERATE 5	HIGH 7	HIGH 9	MODERATE 5	MODERATE 5	MODERATE 5	HIGH 9	HIGH 7
Media Disposal Costs	HIGH 7	HIGH 9	MODERATE 7	MODERATE 5	LOW 3	LOW 3	NONE 0	LOW 3	LOW 3	MODERATE 5	NONE 0	NONE 0
Ability for selective stripping	HIGH 1	LOW 7	HIGH 1	HIGH 1	LOW 9	LOW 9	MODERATE 5	MODERATE 5	LOW 9	MODERATE 5	LOW 9	LOW 9
RESULTS	79	112 (*)	66	60	92 (*)	80(*)	79	105	101	103	82	98
RANK	3	*	2	1	*	*	3	9	7	8	5	6

- Financial aspects:
  . development costs,
  . investment costs,
  . operating costs,
  . waste processing costs.

2.5 - Evaluation

The method chosen consisted in evaluating each process for the criteria retained. This evaluation was made, on the one hand, from available information and results and, on the other hand, from incomplete or partial information due to lack of results or simply because the tests are still in progress.

The values allocated to each criterion range from 0 to 10; 0 corresponds to the best result, 10 to the worst result.

After evaluating all the criteria, the values obtained were added together. The sum obtained represents the score obtained by the process. The best process is supposed to be one with the lowest score.

However, processes with a characteristic or a specificity incompatible with stripping aircraft external paint systems were eliminated from the final classification.

The results obtained show that the 5 processes which obtained the best scores were in decreasing order:

- DMB + starch media,
- PMB + type II media,
- solvent-based, non-phenolic, slightly chlorinated strippers (associated with the barrier coat system),
- Xenon lamp + CO_2 ice pellet blasting,
- LASER.

Other aircraft manufacturers have made evaluations of this type.
From available information, it seems that the results of AEROSPATIALE's and BOEING's evaluations are similar and often oppose the results obtained by Mc DONNELL DOUGLAS.

Nevertheless, the results obtained can be considered as fairly reliable for the first 5 processes. Their classification may change as results from various research programs become available. As for the other processes, follow-up must be continued in order to benefit from any improvements which may be made.

2.6 - Conclusion

From an overall cost-type approach, it is possible to conduct a comparative evaluation of the various existing stripping processes or those under development.

However, the economical conditions, social legislation and means available are not the same for everyone.

To this, we must add the strategies and policies specific to each company which, for some, make it more advantageous to invest and perform the work in-house whereas, for others, it is more advantageous to outsource and benefit from more advantageous conditions.

Standardization Work

Mr. Olivier Malavallon
Aérospatiale
Direction des Etudes
A/DET/CG-MP
Toulouse Est. 316 route de Bayonne
31060 Toulouse Cedex 03
FRANCE

1 - ORIGINS

For several years now, the main civil aircraft manufacturers (AIRBUS and its partners, BOEING, FOKKER, Mc DONNELL DOUGLAS) have been working jointly on the writing of technical recommendations and the drawing up of an international standard. This work concerns the evaluation of the processes and products used to strip aeronautical paint systems.

This procedure was initiated on request from the main airlines. In effect, the airlines are faced with situations in which the financial and operational objectives are becoming increasingly important.
The need was felt to rationalize and, if possible, harmonize the criteria and technical requirements of the various civil aircraft manufacturers in order to facilitate in-service maintenance of the fleets of airlines operating AIRBUS, BOEING, DOUGLAS aircraft, etc..

2 - IATA TASK FORCE

In December 1990, a task force was set up within IATA, including mainly aircraft manufacturers and airlines. This commission was given the objective of encouraging the development of alternatives for stripping coatings applied to the structures of commercial aircraft. The clearly defined aim is to obtain stripping processes meeting economical, environmental and technical requirements.

In January 1993, a document entitled «IATA guidelines for evaluation of aircraft paint stripping materials and processes» was edited.
This document first of all summarizes the technical requirements for the stripping of paint. It then details the technical specifications for each substrate family (metallic or composites) specifying the test methods, the test specimens and the requirement levels to be reached.
For metallic substrates, this mainly concerns:

- paint adherence,
- cladding,
- permanent deformation,
- fatigue strength,
- crack detection,
- corrosion (sandwich, immersion, galvanic, H2 embrittlement).

For composite material substrates, their behaviors were studied visually and mechanically using, in particular, the tensile test.
This IATA Paint Stripping Task Force completed its work in June 1993.

3 - ISO STANDARDIZATION

When the IATA Guidelines had been published, it was decided to continue the work by creating an international standard. Thus, in September 1993, a working group was formed under the ISO organization (ISO/TC20/WG8). The composition of this work group is more or less the same as that of the IATA Task Force.

The aim of this work group is to produce an international standard which can be used as reference for evaluating and qualifying stripping products and processes.

This standard is being drawn up on the basis of the IATA Guidelines and care is being taken to minimize modifications. However, the aircraft manufacturers realized that the section relevant to composite materials would have to be reconsidered and redone.

Today, the draft standard concerning metallic substrates has been finalized and distributed. As for the composite material section, the first draft drawn up by the aircraft manufacturers has been distributed and is now in the finalization stage.

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

Future Prospects

Mr. Olivier Malavallon
Aérospatiale
Direction des Etudes
A/DET/CG-MP
Toulouse Est. 316 route de Bayonne
31060 Toulouse Cedex 03
FRANCE

The technical presentations made within the scope of these «Lecture Séries N° 201» allow us to have an overall view of the work and achievements relevant to the stripping processes which must be both efficient and ecologically-friendly.

Concerning the destiny of these processes and their use in the future, it would be desirable to identify and take the main influencing factors into account.

1 - MARKETS

During the last ten years, the number of military or civil aircraft in service has been steadily increasing. Today, there are around several tens of thousands. Although airlines have used subcontractors for many years now, it is only recently that the armed forces have began to subcontract stripping and painting work to specialized companies which, in certain cases, can operate in-situ.

Recourse to specialized subcontracting can be explained by the cost and cycle gains thus obtained which, today, increasingly influence decisions taken.

2 - AIRCRAFT

Several types of aircraft are to be considered. They can be split into 3 main categories.

- The first category
  Includes small-size aircraft, with highly developing forms, generally with many inspection doors on the exterior, in certain cases with special coatings and often using composite material structures.

  This category mainly includes :
  - helicopters,
  - small liaison and touring aircraft,
  - executive aircraft,
  - fighters.

- The second category
  mainly concerns large-size aircraft with surfaces of fairly regular and continuous forms, with metallic or composite substrates.

This category includes :

- Civil transport aircraft such as those manufactured by AIRBUS, BOEING, DOUGLAS, etc.,
- Military transport aircraft, patrol aircraft, tanker aircraft, etc.,

- The third category
  is halfway between the two previous categories. Although the limits of this category are imprecise, it very clearly concerns regional transport and liaison aircraft or medium-size transport aircraft such as those manufactured by :

  - ATR,
  - British Aerospace,
  - CASA,
  - DORNIER
  - FOKKER, etc...

3 - PROCESSES

Certain processes are more appropriate than others. This depends on the surfaces to be treated, the dimensions, accessibilities, forms and substrates.

Thus, for the second category (large aircraft), semi-automatised processes seem overall to be the most efficient.

However, for the first category (small aircraft), manual procedures seem to be the most practical and most efficient pending, perhaps, the development of high-performance and (very) costly automated equipment which could, in part, replace the work done by man.

Lastly, for the third category (medium aircraft), choice of processes and methods are not so obvious and depend on external criteria such as :

- investments and equipment available,
- additional presence of category 1 or category 2 aircraft in the fleet considered,
- hygiene and safety constraints,
- etc ...

4 - INVESTMENTS

On account of the current economic situation, it seems difficult and risky to invest millions of US dollars in the development and fine-tuning of new technologies and new stripping facilities.

The validation costs for current solutions are relatively high. The number of developments and processes will therefore probably remain constant or fall.

In addition, the potential customers - airlines, specialized companies and air forces - are also faced with highly regulated investment credits and reduced amortization times.

Paper presented at the AGARD SMP Lecture Series on "Environmentally Safe and Effective Processes for Paint Removal" held in Lisbon, Portugal, April 27-28, 1995; Eskisehir, Turkey, May 1-2, 1995 and Ottobrunn, Germany, May 4-5, 1995 and published in LS-201.

Lastly, choices and industrial policies concerning, for example, recourse to subcontracting, relocating activities, etc., are and will be governed by social, economic and legislative constraints.

5 - LEGISLATION

In the future, it seems probable that European, North American and Asian legislations will impose (very) severe constraints for the environment and hygiene-safety. Emissions of volatile polluants, discharges, waste and storage may reach processing coats such that certain solutions will have to be abandoned.

Also, on account of foreseeable developments in ecological sensitivities, the brand name and the reputation of such or such a user may be placed in jeopardy if he is known as being a polluter.

Nevertheless, today, a certain amount of caution is required and even a certain wait-and-see policy is being pursued.

Bibliography

This bibliography has been prepared by the NASA Center for AeroSpace Information (CASI)[1], to support the Lecture Series 201: 'Environmentally Safe and Effective Processes for Paint Removal.' It includes selected reports, papers, books, and other items entered in the NASA STI Database from 1973 through 1994.

[1] Identification numbers 93A (or N) 12345, are NASA accession numbers and may be used to order copies of the cited documents from NASA CASI, via address, phone, fax, or Internet as follows: 800 Elkridge Landing Road, Linthicum Heights, MD 21090-2934 USA, (301) 621-0390, (301) 621-0134 or help@sti.nasa.gov.

Biological treatment of T-38 paint stripping wastes
73N74723
MUELLER, J. A.; HEINEMANN, J. M. 46 pages Avail: CASI HC A03/MF A01

Compatibility of aircraft operational fluids with a graphitepoxy composite: Development of an exterior coating system and remover
81N11120
CLARK, K. G. 43 pages Avail: CASI HC A03/MF A01
The objective of this investigation is the identification of aircraft operational and specialty chemical which are potentially detrimental to the integrity of organic matrix composites. In this report, results of several studies made with the graphitepoxy Hercules AS/3501-6 are disclosed. Several alternatives to the problem of paint removal are discussed. It is concluded that water and maintenance fluids containing water produce significant plasticization of graphitepoxy, while most solvents, oils, hydraulic fluids, and fuel cause no significant mechanical losses. Paint removal was found to be a significant problem due to the activity of chemical removers. Removal is complicated by the fact that stripping thermoset coatings from graphitepoxy is more difficult than stripping from aluminum. A 'weak link' coating system using a nitrocellulose primer is, thus far, the best strippable composite coating if used with the simple methylene chloride remover designated 4-70-1. It is recommended that confirmational testing with tensile, flexure, compression, fatigue and dynamic mechanical specimens of graphitepoxy and possibly some adhesive, be made. Following these tests, the nitrocellulospolyurethane coating system should be field tested on graphitepoxy aircraft substrates.

Self resonating pulsed water jets for aircraft coating removal: Feasibility study
83N13292
CHAHINE, G. L.; JOHNSON, V. E., JR.; FREDERICK, G. S. 90 pages Avail: CASI HC A05/MF A01
The objective of this project was to investigate the feasibility of disrupting a high pressure water jet into a discrete train of well organized slugs through passive acoustic self-excitation of the jet, and as a result to enhance the ability of the jet to remove aircraft coatings and to prepare surfaces for recoating. This innovative technique takes advantages of the water hammer pressures produced by the slugs' impact (which are much higher than the stagnation pressures generated by a continuous jet), without the drawbacks of having a mechanical rotating interrupter. In addition this technique provides larger working standoff distances, wider areas of impact and thus greater control of the energy imparted to a target than a cavitating jet. It is therefore capable of overcoming the drawbacks of existing water jet methods in preparing aircraft surfaces for repainting and of providing a primary supplement if not a practical replacement for chemical removal methods.

Improved paint removal technique
84N19580
MANK, J. F.; DICK, R. J.; ABRAMS, H. C.; NOWACKI, L. J. 151 pages Avail: CASI HC A08/MF A02
The project was initiated with a brief visit to Robins Air Force Base to review their aircraft paint stripping operation. After that project initiation visit, Battelle contacted commercial airlines, aircraft manufacturers, military bases, contract stripping companies, and stripping chemical manufacturers to determine what the state-of-the-art is in the field of stripping paint from aircraft. Many personal visits to stripping facilities were made to get first-hand information from the people involved with stripping aircraft and to see the actual stripping facility. A summary of the information obtained from these contacts is provided in the appendix of this report. The complete stripping of a C141 at Robins Air Force Base and the partial stripping of a KC-135 at Tinker Air Force Base were observed. The intent was to identify specific items and practices in the Warner Robins ALC operation that could be improved in order to decrease the amount of time required to strip an aircraft and therefore increase throughput. It was concluded that Warner Robins is essentially up with the state-of-the-art of airplane paint stripping that has been observed at other stripping facilities.

Laser paint removal
85N11989
MALLETS, T. In Defense Systems Management Coll. DoD Robotics Appl. Workshop Proc. (SEE N85-11978 03-01) 4 pages Avail: CASI HC A01/MF A04
The Laser Paint Stripper program is a three phase effort which includes: feasibility demonstration; prototype optimization; and implementation at our Air Logistic Centers (depots) by FY88. Major technical areas that make up the automated system include: (1) laser device with power and uptime to handle the number and size of aircraft (F-16 vs C-5A); (2) the beam transport and manipulation system; (3) controls for beam/aircraft safety, alignment, and surface condition sensors; (4) integration software; and (5) cleanup of residue products.

Plastic media blast best for stripping
86A26274
BULLINGTON, J. B. (U.S. Army, Production Engineering Div., Corpus Christi, TX) ManTech Journal, vol. 10, no. 4, 1985. 8 pages
A new cost-effect technique for paint stripping, which complies with nonpollution and safety standards is examined. The plastic media blast (PMB) process of removing acrylic and lacquer topcoats from epoxy prime surfaces, which is applicable to airframes, tail rotors, and composites, is analyzed; the advantages of the PMB technique are discussed. The need to prevent media and dust contamination of specific aircraft components is investigated. The design of the standard cabinet-type continuous-flow dry air blasting machine used in the PMB process is described.

Stripping and painting a plane - Technological and economic aspects
86A47614
CAVALLINI, A. (Alitalia, Rome, Italy) IN: AIRMEC '85 - Aviation equipment servicing: Aircraft and helicopter maintenance; International Exhibition and Conference, 4th, Duesseldorf, West Germany, February 26-March 3, 1985, Conference Reports (A86-47601 23-01). Duesseldorf, West Germany, Duesseldorfer Messegesellschaft mbH, 1985. 30 pages
A correct stripping operation is an absolute prerequisite for achieving good results in an aircraft repainting job. The nature of stripping agents, production of toxic fumes, and the disposal of the stripping residuals are discussed, together with the construction specifications of a special stripping/painting hangar and the means of reducing the ground time for the aircraft to the essential minimum. To achieve good adhesion of paint and finish, the installation of an air conditioning system capable of maintaining strictly controlled temperature and humidity was found to be a necessity. Correct thickness and good finish characteristics were achieved using airless electrostatic applicators, which could be positioned over each platform and could be interconnected and moved along the fuselage. The conditions of drying, when no operator is allowed inside the hangar, could be controlled from the control center. A dual-color TV system permits a supervisor to control and coordinate the entire stripping/painting operation.

Evaluation of the effects of a plastic bead paint removal process on properties of aircraft structural materials
86N26384
CHILDERS, S.; WATSON, D. C.; STUMPFF, P.; TIRPAK, J. 151 pages Avail: CASI HC A08/MF A02
An abrasive blasting process using plastic beads has been proposed for removing organic coatings from aircraft surfaces and component parts. During the prototype development of the plastic bead blasting process for paint removal many concerns surfaced relative to the potential effects of the process on metal and composite aircraft structural materials. This evaluation of the plastic bead blasting paint removal showed that it removed protective metal coatings such as aluminum cladding and anodize coatings from aluminum alloys and cadmium plating from steel structure. Surface roughness resulted on clad aluminum alloys. Warpage as a result of surface cold working occurred on unsupported thin skin metal materials. The bond strength of thin skin adhesive bonded structure was not affected. The process is less damaging in fatigue to 7075-T6 aluminum structure blasted at 60 psi nozzle pressure than at 38 psi nozzle pressure. Epoxy/graphite composite structure which was plastic bead blasted showed statistically significant losses in the matrix dominated properties. No significant reductions occurred in the fiber dominated mechanical properties.

Paint removal process
86N26436
ROBERTS 13 pages Avail: CASI HC A03/MF A01
A process of stripping paint from aluminum employs plastic particulate having sharp edges, having a hardness of about 3.5 on the mohs' scale and having a range of sizes from about 30 to 40 U.S. standard sieve. This media strips aluminum without abrasion at a pressure of about 25 to 40 pounds per square inch at the nozzle. Other substrates other than soft plastic can be stripped without damage.

Localized coating removal using plastic media blasting
88A52369
NOVAK, HOWARD L.; WYCKOFF, MICHAEL G.; ZOOK, LEE M. (NASA, Kennedy Space Center; USBI Booster Production Co., Cocoa Beach, FL) IN: Space Congress, 25th, Cocoa Beach, FL, Apr. 26-29, 1988, Proceedings (A88-52317 23-12). Cape Canaveral, FL, Canaveral Council of Technical Societies, 1988. NASA-supported research. 8 pages
Steps taken to qualify the use of plastic media blasting for safely and effectively removing paint and other coatings from solid rocket booster aluminum structures are described. As a result of the effort, an improvement was made in the design of surface finishing equipment for processing flight hardware, in addition to a potentially patentable idea on improved plastic media composition. The general arrangement of the blast equipment and the nozzle configuration are presented.

Plastic media blasting recycling equipment study
89N21987
81 pages Avail: CASI HC A05/MF A01
Plastic Media Blasting (PMB) is a new technology introduced as a candidate to replace wet chemical paint stripping of airframes and component parts. This report documents the physical testing, observations, and laboratory analyses used to evaluate the effectiveness of plastic media recycling equipment at three PMB sites. Different systems for recycling plastic media were evaluated for operational performance, losses, efficiency, and metal removal. An optimum recycling system was selected which included a cyclone for gross air/media separation, a vibrating screen to remove extra large and extra small particles, and a self-cleaning magnetic separator for ferrous particle removal.

The effects of plastic media blasting paint removal on the microstructure of graphitepoxy composite materials
89N22688
KOZOL, JOSEPH; THOMAN, STEVEN; CLARK, KENNETH 45 pages Avail: CASI HC A03/MF A01
Plastic media blasting (PMB) was assessed as a paint removal method for AS4/3501-6 and IM6/3501-6 graphite epoxy (Gr/Ep) composite materials. Microstructural effects on these composite materials were evaluated after repeated paint/blast cycles.

Polyester (type 1) and urea formaldehyde (type 2) plastic media materials were used in a variety of blast conditions. Ultrasonic inspection, optical microscopy and scanning electron microscopy were used to assess the damage induced during paint removal. After one paint/blast cycle, most of the blast conditions caused little or no visual damage to the composite substrates. After four paint/blast cycles, several of the conditions caused minimal visual damage. Paint removal by sanding caused more visual damage after one paint removal cycle than any of the repeat blast conditions that were evaluated.

Accustrip - The next generation in nontoxic low impact stripping
90A24686
LEE, RICK C.; KIRSCHNER, LARRY SAE, Annual AerospacAirline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 14 pages
Accustrip: a new 'wet stripping' process that allows depainting in existing chemical stripping facilities utilizes a proprietary blend of sodium bicarbonate as a media along with a mixture of air and water. The media is manufactured and blended as food grade quality. The process has several major benefits. It has very low dust emissions, removes oil and grease, and has ability to remove surface corrosion from metal substrates during stripping without additional steps or materials. The blended sodium bicarbonate is nontoxic to the worker and environment. Economics of the media do not require costly reclaim facilities or dust collecting systems. Disposal costs are minimal.

Robotic dry stripping of airframes - Phase II
90A24691
PAULI, ROBERT A.; WITTENBERG, ART M. (Pauli and Griffin Co., Vacaville, CA); (Air Canada, Quebec) SAE, Annual AerospacAirline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 10 pages
This paper describes a program for the development of a dust-free closed-cycle robotic system for dry stripping of airframes, designed to insure dust-free work environment and reduce plastic-media loss, the contamination risk, and the media inventory requirement. Phase I of the program involved building a prototype of the proposed robotic arm and its dust enclosure to prove basic automation concepts, showing reasonable paint removal rate from a curved surface, and establishing that the process is dust-free and recovers plastic media in a closed-cycle fashion. This paper contains calculations on the effect of different blasting parameters in order to determine optimum values required for the completion of Phase I. Also presented is the progress achieved by the Phase II of the program, which is to prove the total concept by building the complete system and demonstrating its capability.

Automated aircraft paint strip cell
90A24699
BYERS, THOMAS EDWARD; PAULI, ROBERT (USAF, Ogden Air Logistics Command, Ogden AFB, UT); (Pauli and Griffin Co., Vacaville, CA) SAE, Annual AerospacAirline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 12 pages
The development of an automaterobotic stripping process for F-4 and F-16 aircraft is discussed. The selection and optimization processes involved the evaluation of various stripping methods prior to selecting the plastic media blast procedure. The design and requirements for the Robotic Paint Stripper Cell (RPSC) and the testing of a prototype are described. The installation and verification phase of the project is examined. Diagrams of the RPSC are provided.

Automating and controlling dry paint stripping
90A24702
CUNLIFFE, F. R., III (Aerolyte Systems, Burlingame, CA) SAE, Annual AerospacAirline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 11 pages
The key parameters which affect the efficiency and success of the dry paint-stripping process are discussed, including pressure at the nozzle, the size of the nozzle, the angle of blasting, the distance from the work-piece, the hardness and the size of the media, and the media flow. It is pointed out that, by automating the dry paint stripping process, many of these parameters can be controlled, making it possible to reproduce the same result, time and again. Attention is given to a recently developed automated aircraft wheel stripping machine, whose units are operated by joy stick controls from outside the cabinet. The wheel can be rotated and moved forward and backward in order to gain access to all of the surfaces; the operator also controls the nozzle manipulator which is a five-axis unit. At present, robotic systems are being developed for small aircraft and for the jumbo jets in use throughout the commercial airline fleets of the world.

Determination of effects of plastic medium blast on surface-crack detection by fluorescent penetrant inspection in wrought aluminum alloys
90A45224
CONRAD, D. A.; CAUDILL, G. R. (U.S. Navy, Materials Engineering Div., Norfolk, VA) Materials Evaluation (ISSN 0025-5327), vol. 48, Aug. 1990. 7 pages
The effect of plastic medium blasting (PMB) on the deformation of preexisting surface cracks was investigated using fluorescent penetrant inspection (FPI) process to measure the crack length. It was found that, when PMB was used to remove coatings, subsequent etching was critical to effective surface-crack detection by FPI. The observed changes in crack lengths were found to be due to two phenomend: the intrusion of medium into the crack and the closure. Restoration of cracks was demonstrated by subjecting the blasted surface to an etching process. The relative detectability of surface cracks after PMB paint removal was compared with that for chemical paint removal.

Plastic media blast (PMB) paint removal from composites
90A50162
BUTKUS, LAWRENCE M.; MEUER, GARY D.; BEHME, ARTHUR K., JR. (USAF, Materials Laboratory, Wright-Patterson AFB, OH); (Dayton, University, OH) IN: International SAMPE Symposium and Exhibition, 35th, Anaheim, CA, Apr. 2-5, 1990, Proceedings. Book 2 (A90-50056 23-23). Covina, CA, Society for the Advancement of Material and Process Engineering, 1990. 13 pages
Plastic media blasting (PMB) for use on graphitepoxy composites was compared with the manual sanding method to determine the possible damage to surfaces. It was shown that, using PMB on metal and composite airframe surfaces could streamline stripping operations, reduce health hazards, and eliminate the possible damage chemical strippers may cause. PMB was found to be a viable, less damaging paint removal method than manual sanding, provided some precautions are taken. Nondestructive evaluation, mechanical testing, and scanning electron microscopy of stripped and unstripped (baseline) graphitepoxy panels was performed to determine the effects caused by a single application of PMB and "hand" sanding. Experiments identified safe combination of PMB parameters, including: media size and hardness, standoff distance, angle of incidence, and nozzle pressure.

Ultrasonic assisted paint removal method
90N16479
REINHART, THEODORE J. Filed 7 Jul. 1987 Supersedes US-Patent-Appl-SN-070499 9 pages Avail: US Patent and Trademark Office
This abstract discloses paint or other protective coating removal method involving the use of reciprocal motion ultrasonic frequency mechanical energy applied to the coating by a variety of tool and abrasive substrate members in the company of surface preparation agents, such as coolant, heating, softening, and/or abrasive agents. The invention is particularly applicable and disclosed in terms of, protective coating removal from aircraft such as is often necessary for replacement or in the reutilization of aircraft with different identification markings. The coating removal method is environmentally and human operator safe in comparison with presently used coating removal methods such as abrasive blasting and chemical solvent removal.

The future of aircraft paint removal methods
90N16936
THEN, MICHAEL J. 169 pages Avail: CASI HC A08/MF A02
The purpose of this study was to develop a qualitative forecast for predicting aircraft paint removal methods. A Delphi methodology was used to create a technical forecast, combining the expectations of individuals who work with the related technologies on a daily basis. The Delphi results yielded five major conclusions. First, the projected paint removal method that will suit future paint removal needs is Plastic Media Blasting (PMB), and no other method is projected to be a serious threat to PMB's dominance. Second, PMB's process and parameters must be further researched to optimize the method's effectiveness. Third, the worker's safety can be further enhanced by both protective equipment that is available today, and facility construction that is specifically designed for the given removal method. Fourth, facility design is the major consideration when defining a paint removal's environmental effects. Lastly, it is undeterminable if robotics will replace human labor. Equipment that safely applies PMB is available today, while the equipment that further the method's effectiveness of separating heavy particles will be accessible in 1 year.

Mechanical paint removal techniques for aircraft structures
90N25254
AMRO, J. P. 97 pages Avail: CASI HC A05/MF A02
Paint removal was studied by mechanical means, i.e., blasting, from aluminum structural aeronautical materials (2024-T3) and the changes on the surface morphology introduced by the paint removal process are examined. The principal experimental parameters are particle velocity, and particle angle of incidence. An ideal combination of these parameters could yield a stripped aircraft skin substrate with minimal or no damage. Three types of plastic particles were used are: Polyextra, Polyplus, and Type III. Scanning electron microscopy has shown that a potentially damaging surface morphology is formed on the surface of the structural material. Multiple microcracks or fissures generated by the stripping could reduce the life and/or change the engineering properties of the material. It as also found that aluminum material stripped using plastic media particles has a very rough surface that may affect the aerodynamic flow of an airplane. The number of microcracks and degree of surface roughness vary with the particle impact angle and velocity. To minimize or eliminate the damage done to the surface during the plastic particle stripping, it was necessary to change the blasting media to softer and smaller particles. Commercial wheat flour was selected for this purpose. With the substitution of these natural particles, the scanning electron microscopy observations of the stripped surface revealed no potential damage (microcracks or fissures) on the structural material, and the surface roughness was also reduced.

Mechanical paint removal techniques for aircraft structures
90N26166
AMRO, JOE P.; TALIA, JORGE E. Presented at the 1990 AIAFAA Joint Symposium on General Aviation Systems 20 pages Avail: CASI HC A03/MF A01
Paint removal by mechanical means, i.e., blasting, from aluminum structural aeronautical materials (2024-T3) was examined alone with the changes on the surface morphology introduced by the paint removal process. Three types of plastic particles were

used in this research: Polyextra, Polyplus, and Type III. Scanning electron microscopy has shown that a potentially damaging surface morphology is formed on the surface of the structural material. Multiple microcracks or fissures generated by the stripping could reduce the life and/or change the engineering properties of the material. It was also found that aluminum material stripped using plastic media particles has a very rough surface that may affect the aerodynamic flow of an airplane. The number of microcracks and degree of surface roughness vary with the particle impact angle and velocity. To minimize or eliminate the damage done to the surface during the plastic particle stripping, it was necessary to change the blasting media to softer and smaller particles. Commercial wheat flour was selected for this purpose. With the substitution of these natural particles, the scanning electron microscopy observations of the stripped surface revealed no potential damage (microcracks or fissures) on the structural material, and the surface roughness was also reduced.

Automatic aircraft paint stripping
91A36895
STURDIVANT, VERNON R. (Southwest Research Institute, San Antonio, TX) Society of Manufacturing Engineers, Conference on Aerospace Automation and Fastening, Arlington, TX, Oct. 9-11, 1990. 12 pages
Paint must be removed from aircraft to allow detailed surface inspection, to perform repair operations, and to keep weight at acceptable levels after many coats of paint have been applied. Southwest Research Institute is presently constructing a robotic system for automatically removing paint from fighter aircraft for the United States Air Force. The process removes paint by plastic media bead blasting. The blast nozzles are positioned over the aircraft surface with a robot. The system consists of two, 9 degree-of-freedom (DOF) robots together with two robot controllers, one cell control computer, paint sensors, and bead blasting equipment.

Robotic sensors for aircraft paint stripping
91A36896
WENIGER, RICHARD J. (Southwest Research Institute, San Antonio, TX) Society of Manufacturing Engineers, Conference on Aerospace Automation and Fastening, Arlington, TX, Oct. 9-11, 1990. 12 pages
Aircraft of all types need to have paint routinely removed from their outer surfaces. Any method needs to be controlled to remove all the paint and not damage the surface of the aircraft. Human operators get bored with the monotonous task of stripping paint from an aircraft and thus do not control the process very well. This type of tedious operation tends itself to robotics. A robot that strips paint from aircraft needs to have feedback as to the state of the stripping process, its location in respect to the aircraft, and the availability of stripping material. This paper describes the sensors used on the paint stripping robot being developed for the United States Air Force's Manufacturing Technology Program. Particular attention is given to the paint sensor which is the feedback element for determining the state of the stripping process.

Paint stripping in the aerospace industry
91A49159
WOLF, KATY (Institute for Research and Technical Assistance, Los Angeles, CA) IN: International SAMPE Technical Conference, 22nd, Boston, MA, Nov. 6-8, 1990, Proceedings (A91-49101 21-23). Covina, CA, Society for the Advancement of Material and Process Engineering, 1990. 7 pages
Methods available for paint stripping of aerospace structures and other industrial equipment are discussed. Special attention is given to the following alternatives: methylene chloride-based chemical strippers, cryogenic striping, plastic media blasting, sodium bicarbonate stripping, and not painting at all.

Proceedings of the 2nd E-3 AWACS Corrosion Prevention Advisory Board (CPAB)
91N15150
Meeting held at Tinker AFB, OK, 12 Jul. 1990 141 pages Avail: CASI HC A07/MF A02
Two environmental issues in particular are affecting all USAF weapons systems and is being felt by FMS weapons systems as well (particularly in Germany). These are volatile organic compounds (VOCs), and non-chemical paint removal. Topics include: problems with waterborne primers, MIL-P-85582; comparison of plastic materials, MIL-P-85891 (Dupont lease agreement); use of high solids polyurethane topcoat, MIL-C-85285; and qualification of materials.

The effect of paint removal by natural bead blasting on the surface morphology of composite materials
91N15335
GUY, THU-HA; LANKARANI, HAMID M.; TALIA, JORGE E. 19 pages Avail: CASI HC A03/MF A01
Paint removal by blasting and its effects on the surface morphology of the composite material were investigated. Plastic media blasting (PMB), used extensively by many as a paint removal method, showed potential microstructural damage. However, natural particles seemed to be a better choice for paint removal by blasting since they were softer and smaller in size; thus, minimizing the amount of damage to the surface of the composite. The variation of the degree of roughness and amount of broken fibers were correlated with the parameter of impact angle to obtain an optimum environment for paint removal by blasting.

Design of a wall-scaling robot for inspection and maintenance
91N15557
BAHR, BEHNAM; MAARI, SAMI M. 10 pages Avail: CASI HC A02/MF A01
The design of a new wall-scaling robot for the inspection and maintenance of various structures,

such as aircraft or nuclear power plants, is described. This robot is capable of climbing straight or curved surfaces in two directions, up/down or left/right in strokes of 55 mm. The load carrying capability of this robot is about 100 kg. Thus, it can carry a variety of non-destructive testing devices for inspection, paint removal, and de-riveting devices for maintenance. The robot uses vacuum suction cups for sticking to the surface of an object and can be integrated with a vision sensor system for guidance and visual inspection. The positioning of the robot is achieved by the use of a joy-stick or a PC computer. With this portable robot it is possible to: (1) inspect areas that are within easy reach; (2) program the robot to follow a specified path while inspecting or maintaining the structures; and (3) remotely guide it to desired locations. This robotic system will minimize human error, increase the productivity of an inspector, and reduce the cost of inspection and maintenance.

Use of natural particles for the removal of paint from aeronautical composite materials
91N18015
GUY, THU-HA; LANKARANI, HAMID M.; TALIA, JORGE E. In its Proceedings: Techfest14 (SEE N91-18004 10-01) 1 pages Avail: CASI HC A01/MF A01
Paint removal by blasting and its effects on the surface morphology of aeronautical composite materials are investigated. An ideal combination of the parameters for mechanical paint removal by blasting such as particle type, size, velocity and angle of incidence yields a stripped aircraft skin substrate with minimal or no damage. Natural particles, specifically white corn flour, seem to be a good choice for paint removal by blasting. Since they are softer as well as smaller in size than other particles used for paint removal, they minimize the amount of damage to the surface of the composite. They are also cheaper and produce no harm to environment. The variation of the degree of surface roughness and the amount of broken fibers were correlated with some stripping parameters, such as particle impact angle and velocity. This defined an optimum environment for paint removal by blasting.

Mechanical paint removal techniques for composite aircraft
91N24163
TALIA, JORGE E.; BAHR, BEHNAM; BECKER, WAYNE; LANKARANI, HAMID M. In its Program Plans for Aviation Safety Research (SEE N91-24157 16-03) 6 pages Avail: CASI HC A02/MF A01
The use of conventional paint removal on composite material can lead to a fast deterioration or weakening of the material due to the absorption and chemical attack of the solvent which may result in a catastrophic failure of the structure. Moreover, recent EPA regulations ban the use of solvents for paint removal on land and sea military bases. The objective is to investigate the possibilities of paint removal by mechanical techniques, specifically by the impingement of solid particles, a technique that would not leave structural damage on the treated material and would not effect the environment.

The evaluation of the effects of a plastic bead blasting paint removal process on graphite-epoxy composites
92A10150
WIDAUF, DAVID P. (Utah State University, Logan) IN: International SAMPE Symposium and Exhibition, 36th, San Diego, CA, Apr. 15-18, 1991, Proceedings. Book 1 (A92-10126 01-23). Covina, CA, Society for the Advancement of Material and Process Engineering, 1991. 11 pages
Experiments were carried out on 12-ply graphitepoxy panels to investigate the effect of paint removal by plastic bead blasting on the physical properties of the composite. The evaluation included tensile testing, flexural testing, and SEM and ultrasonic examinations. The graphitepoxy composites exhibited statistically significant losses in the matrix-dominated properties while no significant losses were observed in the fiber-dominated properties. No significant differences were found in strength and modulus among the panels.

The operational status of automated aircraft washing system
92A56087
SOGA, TOMOKATSU (Japan Airlines Co., Ltd., Tokyo) IN: Aircraft Symposium, 29th, Gifu, Japan, Oct. 7-9, 1991, Proceedings (A92-56001 24-01). Tokyo, Japan Society for Aeronautical and Space Sciences, 1991. In Japanese. 4 pages
The performance and configurations of an automated aircraft washing facility are presented. The brushing area, the operation time, and rinsing are controlled in this computerized washing system.

Paint removal using cryogenic processes
92N28912
KIRTS, RICHARD E.; STONE, PHILIP L. 44 pages Avail: CASI HC A03/MF A01
The use of a high-pressure jet of cryogenic fluid (e.g., liquid nitrogen at -320 F) to remove paint and other protective coatings from Navy aircraft and ships was studied. The objective of the work was to explore the feasibility of developing a paint removal method that is less harmful to the environment than the chemical paint stripping methods presently in use. It was learned that only thick (t greater than 0.020 inch) films of paint can be effectively removed by the mechanism of thermal shock. Aircraft paint is too thin and flexible to be removed by cryogenic methods. Cryogenic methods are not recommended for use on ships because of the danger of steel embrittlement by low temperatures. It was demonstrated that a jet of liquid nitrogen can effectively remove certain paints (regardless of thickness) by the mechanism of differential thermal contraction. The process may

have application where control of paint waste is essential, for example, removal of thick films of lead base paint.

Laser paint stripping
92N29581
HEAD, J. D.; NIEDZIELSKI, J. PETER 102 pages
Avail: CASI HC A06/MF A02
A study to assess the utility of high powered CO2 pulsed laser depainting methods was conducted on aluminum and graphite epoxy composites. The various tests were designed to detect potential forms of damage or loss of properties of various aircraft structural materials during removal of paint with pulsed laser energy. Tests for changes in physical properties, paint adhesion and corrosion protection of repainted materials showed no detectable adverse changes in any of the samples studied.

Automated laser depainting of aircraft survey of enabling technologies
92N70886
KOPF, PETER W.; PICHON, DEAN 261 pages
Avail: CASI HC A12/MF A03
The requirements needed to integrate a laser depainting system into the Oklahoma City Air Logistics Center Depainting Facility were identified and evaluated to determine if the enabling technologies were available to reasonably expect a large robotic laser depainting system could be made and operated in a production environment. Robotic, laser, sensor, and computer control systems were examined, tested, and evaluated.

Dry ice blasting
93A14084
LONERGAN, JEFFREY M. (U.S. Navy, Naval Aviation Depot, San Diego, CA) SAE, Annual AerospacAirline Plating and Metal Finishing Forum and Exposition, 28th, San Diego, CA, Apr. 20-23, 1992. 8 pages
As legal and societal pressures against the use of hazardous waste generating materials has increased, so has the motivation to find safe, effective, and permanent replacements. Dry ice blasting is a technology which uses CO2 pellets as a blasting medium. The use of CO2 for cleaning and stripping operations offers potential for significant environmental, safety, and productivity improvements over grit blasting, plastic media blasting, and chemical solvent cleaning. Because CO2 pellets break up and sublime upon impact, there is no expended media to dispose of. Unlike grit or plastic media blasting which produce large quantities of expended media, the only waste produced by CO2 blasting is the material removed. The quantity of hazardous waste produced, and thus the cost of hazardous waste disposal is significantly reduced.

Coating removal systems - Mobile or fixed?
93A14087
MANGOLD, VERNON L., JR. (Kohol Systems, Inc., Dayton, OH) SAE, Annual AerospacAirline Plating and Metal Finishing Forum and Exposition, 28th, San Diego, CA, Apr. 20-23, 1992. 14 pages
Various coating removal technologies are discussed from the viewpoint of the process and delivery, with emphasis placed on the mobile Large Aircraft Robot Paint Stripping (LARPS) concept. LARPS is a combined and integrated package of a delivery system and the process media, representing the alternative to the fixed-frame or gantry robot style delivery systems. The paper describes details of the LARPS system design and performance, and presents design diagrams of LARPS.

Starch media blasting for aerospace finishing applications
93A14091
OESTREICH, JOHN; PORTER, TODD (Ogilvie Mills, Ltd., Montreal, Canada) SAE, Annual AerospacAirline Plating and Metal Finishing Forum and Exposition, 28th, San Diego, CA, Apr. 20-23, 1992. 9 pages
A wide range of starch blast media coating removal applications for the aerospace industry are reviewed with particular attention given to the coating removal technologies used in commercial and military aircraft maintenance. For commercial aircraft, these coating removal processes include processes for removing coatings from clad aluminum and from composites, removal of interior finishing coatings, and removal of structural and bonding adhesives. For military aircraft maintenance, the processes discussed include the coating removal from aluminum clad surfaces, and from composite parts. Consideration is also given to the removal of coatings and bonding adhesives as part of aircraft manufacture procedures.

Water instead of chemical corrosives against aircraft paint - Environment-friendly paint-stripping methods could mean drastic cost reductions for the aircraft industry
93A21850
New-Tech News (ISSN 0935-2694), vol. 3, 1992. 3 pages
This paper describes an environmentally friendly alternative for removing aircraft paint. The technique utilizes a thin stream of water to strip paint off surfaces. Rotating nozzles fan out the stream so that the aircraft surface remains undamaged despite enormous water pressure.

Dry-ice blasting
93A30768
Aerospace Engineering (ISSN 0736-2536), vol. 13, no. 3, March 1993. 3 pages
Dry-ice blasting technology that uses carbon dioxide pellets as a blasting medium is discussed. It is noted that the use of CO2 for cleaning and stripping operations may provide significant environmental, safety, and productivity improvements over grit blasting, plastic-media blasting, and chemical-solvent cleaning.

The role of paint systems in aircraft maintainability
93A30962
GARDNER, GREGORY A.; BAUMGARDNER, L.

K. (McDonnell Douglas Corp., Saint Louis, MO); (Bridge Associates, Frankfurt am Main, Germany) AIAA, AHS, and ASEE, Aerospace Design Conference, Irvine, CA, Feb. 16-19, 1993. 6 pages
Aircraft paint systems are extremely long-lived and effective. This robust design means that, when they must be removed, these systems present significant difficulties to the maintenance centers facing the task. A summary of the paint-stripping processes available to aircraft overhaul centers shows that relatively cost effective processes can be selected, but that even the best present problems. The conclusion is that the real hope for alleviating this problem involves a redesign of the paint systems to make them more maintainable, not the development of better stripping processes for existing coatings.

Ultra-high pressure water jet technology - An overview of a new process for aerospace paint stripping
93A40661
JOHNSON, SPENCER T. (Jet Edge, Inc., Minneapolis, MN) Society of Manufacturing Engineers, Maintaining and Supporting an Aircraft Fleet Conference, Dayton, OH, June 9-11, 1992. 13 pages
New technology used to develop water pressures of over 50,000 psi is reviewed. The technology uses ultra-high pressure waterjet equipment capable of removing the toughest coating from delicate substrates without damage, using only water.

Sensor-adaptive control for aircraft paint stripping
93A40663
WENIGER, RICHARD J.; FRANKE, ERNEST A. (Southwest Research Inst., San Antonio, TX) Society of Manufacturing Engineers, Maintaining and Supporting an Aircraft Fleet Conference, Dayton, OH, June 9-11, 1992. 10 pages
The difficulty of removing paint from aircraft varies greatly due to factors such as the number of coats, age and condition of paint, and the presence of other coverings such as decals. Efficient automation of paint stripping requires adaptive process control based on sensors that can distinguish between substrate and coating material. This paper describes a sensor for identification of the type and condition of aircraft materials based on the analysis of optical reflectance spectra. The performance of a recently installed robotic depainting system using this sensor for adaptive control of the paint stripping also is described.

Automated Laser Paint Stripping (ALPS)
93A40667
BARONE, PHILIP A. (International Technical Associates, Santa Clara, CA) Society of Manufacturing Engineers, Maintaining and Supporting an Aircraft Fleet Conference, Dayton, OH, June 9-11, 1992. 18 pages
An Automated Laser Paint Stripping program developed by International Technical Associates, Santa Clara, California is described. The program is aimed at designing and fabricating two mobile robot-based laser stripping systems for removing paint from metallic and composite substrates of fighter-sized aircraft. Emphasis is placed on the major cell elements of the ALPS system which include a laser, a robot, a multispectral camera, a rastering system, an end effector, a waste management system, a cell controller, and a safety system.

The effects of high-pressure water on the material integrity of selected aircraft coatings and substrates
93A40668
HARBAUGH, DARCY J.; STONE, M. A. (USBI Co., Huntsville, AL) Society of Manufacturing Engineers, Maintaining and Supporting an Aircraft Fleet Conference, Dayton, OH, June 9-11, 1992. 6 pages
USBI is developing high-pressure water as an alternative technology to replace the current chemical stripping process for aircraft. A critical component for the high-pressure water process is the nozzle assembly. An extensive evaluation of both commercially available and in-house designed nozzle configurations has been done to select nozzles which meet the stringent paint stripping requirements. This paper presents the results of the nozzle optimization work and the materials evaluations performed.

Intelligent control of robotic paint stripping using color vision feedback
94A12324
HARVEY, D. N.; ROGERS, T. W. (MTS Systems Corp., Eden Prairie, MN); (Pratt & Whitney Waterjet Systems, Huntsville, AL) In: Intelligent robots and computer vision XII: Algorithms and techniques; Proceedings of the Meeting, Boston, MA, Sept. 7-9, 1993 (A94-12322 02-63). Bellingham, WA, Society of Photo-Optical Instrumentation Engineers, 1993. 9 pages
The paper describes a color-based machine vision system which is capable of functioning as a real-time process control system for a robotic work cell currently being developed for stripping paint from both large and small aircraft. The system is based on hue, saturation, and intensity representation of the image data and on rapid analysis techniques and is capable of differentiating between painted, primed, stripped, and roughened aircraft surfaces. These techniques were tested on a large number of aircraft paint schemes under actual stripping conditions, and were found to be fast and robust enough for real-time process control.

Environmentally Safe and Effective Processes for Paint Removal
94N10613
The 75th meeting was held in Lindau, Germany, 7-8 Oct. 1992 133 pages Avail: CASI HC A07/MF A02
Paint stripping and repainting of aircraft surfaces are required periodically during the operating lifetime of an aircraft. Historically, paint removal has been achieved with chemical strippers. These materials often contain toxic components and create hazardous

working conditions. It is necessary to ensure that alternate paint removal techniques are available that can be performed in a cost effective, environmentally safe manner without causing damage to aircraft surfaces. For individual titles, see N94-10614 through N94-10629.

Paint removal activities in the US Navy
94N10614
KOZOL, JOSEPH In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 5 pages Avail: CASI HC A01/MF A02
Use of methylene chloride and phenol based chemical strippers for aircraft paint removal generates large quantities of hazardous waste and creates health and safety problems for operating personnel. This paper presents an overview of the U.S. Navy's activities in the investigation and implementation of alternate paint stripping methods which will minimize or eliminate hazardous waste and provide a safe operating environment. Alternate paint removal methods under investigation by the Navy at the present time include use of non-hazardous chemical paint removers, xenon flashlamp/CO2 pellets, lasers and plastic media. Plastic media blasting represents a mature technology in current usage for aircraft paint stripping and is being investigated for determination of its effects on Navy composite aircraft configurations.

Paint removal activities in Canada
94N10615
FOSTER, TERRY In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 3 pages Avail: CASI HC A01/MF A02
Paint removal activities currently under way in Canada include: research and development of laser paint stripping; development and commercialization of a new blasting medium based on wheat starch; commercialization of a new blasting medium and process using crystalline ice blasting for paint removal and surface cleaning; and the development of automated and robotic systems for paint stripping applications. A specification for plastic media blasting (PMB) of aircraft and aircraft components is currently being drafted by NDHQ for use by the Canadian Armed Forces (CAF) and contractors involved in coating removal for the CAF. Defense Research Establishment Pacific (DREP) is studying the effects of various blast media on coating removal rates, and minimizing the possibility of damage to substrates other than aluminum such as graphite epoxy composite and Kevlar. The effects of plastic media blasting on liquid penetrant detection of fatigue cracks is also under investigation.

Procedures without danger to the environment and efficiency (PSDEE) for the removal of paint. Point on the French activities concerning the removal of paint
94N10616
GAUTHIER, PIERRE In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 6 pages Avail: CASI HC A02/MF A02
The text presents a synthesis of the activities and subjects of French interest in new techniques for the removal of paint in the civil and military air transport sector.

Paint removal activities in Germany
94N10617
HOLBEIN, R.; ARNOLDS-MAYER, G. In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 5 pages Avail: CASI HC A01/MF A02
To replace paint removing chemicals containing chlorinated hydrocarbons several alternative paint stripping methods have been developed or are under study in Germany: high pressure water stripping; plastic media blasting; use of alcalic and acid activated softeners; CO2 pellet blasting; and laser application.

The development of alternative paint removal techniques in the RAF
94N10618
HARTLEY, M.; WEEDING, M. In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 8 pages Avail: CASI HC A02/MF A02
Personnel safety and environmental legislation is forcing the removal of chemical removers. The RAF chose the Plastic Media Stripping process as their alternative. During testing of the process a number of problem areas and additional advantages were highlighted. Solution to the problems are discussed and the advantages quantified.

Operational aspects of F.16 plastic media blasting, as carried out by Fokker Aircraft Services
94N10619
POT, FRANK In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 3 pages Avail: CASI HC A01/MF A02
In 1987, Fokker Aircraft Services started F.16 air-intake paint removal by means of Plastic Media Blasting (PMB). Especially for this process, a robot has been developed. In a later stage, complete exterior PMB-paint removal has been tested and successfully adopted. The paint removal is carried out in the scope of a thorough corrosion control program. The requirement that all the paint must be removed in order to allow this control program to be carried out properly, leads to severe masking complications. The process parameters are relatively conservative, because of the requirement that absolutely no anodic layer damage is permitted. Following PMB paint removal, corrosion is removed using aluminum oxide blasting. Finally, a highly flexible polyurethane paint system is applied, based upon TT-P-2760 Koroflex primer. To summarize the process, it can be stated that the plastic media blasting itself is straight-

forward. Proper masking is difficult to perform though, compounded by special customer requirements such as open panel edges.

Use of robots for aircraft dry stripping via plastic media blasting
94N10620
GILLARD, E. In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 6 pages Avail: CASI HC A02/MF A02
In order to meet constant financial and reliability concerns, European manufacturers have introduced more and more composite materials on their aircraft. In addition to fairings for which the use of composites has become absolutely necessary, composites are used on each new program for structures which are more and more highly loaded and sophisticated. Similarly to metallic structures, an external paint scheme is applied to these composite structures to protect them from ultraviolet rays, provide general corrosion resistance and allow the airlines to customize their aircraft. Conventional stripping methods using chemical strippers cannot be used as many impregnation resins do not resist chemical strippers. Aerospatiale has endeavored to find new efficient methods that are easy to implement, cause no damage and are applicable both to metallic and composite structures. Dry stripping via plastic media blasting has formed the subject of many tests. These tests proved that such stripping was compatible with the objectives but required automation of the process for large airframe stripping.

German Air Forces experiences with plastic media blasting and future requirements
94N10621
STOERMER, MATTHIAS In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 14 pages Avail: CASI HC A03/MF A02
German Air Force (GAF) has been researching a method of paint removal for a couple of years to replace the chemical method still in use. This is to improve corrosion prevention, environmental protection and health care. With the support of German aerospace company MBB and the University of the Armed Forces in Munich GAF selected Plastic Media Blasting (PMB) as the most suitable method. Having a stripping facility for the entire aircraft at MBB Manching already in existence, GAF decided that the next step forward to gain more experiences is to establish a smaller 'stripping cabin' at an air force base. This cabin is suitable for stripping removable parts and components of aircraft and equipment with the max. size of a half dismantled TORNADO wing. With these gained experiences GAF will be in position to formulate the specific requirements for an entire on-base aircraft stripping plant which will be suitable for F-4's, TORNADO's and EFA's, too.

Plastic media blasting activities at Hill Air Force Base
94N10622
CHRISTENSEN, J. D. In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 2 pages Avail: CASI HC A01/MF A02
Hill Air Force Base in Utah developed plastic media blasting (PMB) paint removal process for removing paint from Air Force aircraft. The development of the process involved extensive testing of various abrasives and subsequent parameters to end up with an approved production process. Hill AFB has been using PMB in a production mode since 1985, and completely discontinued chemical stripping of airframes in 1989. We have recently installed and began operating a fully automated PMB facility that utilizes two nine-axis robots to strip an aircraft. This system has enabled us to further reduce the manhours required to strip an aircraft, and also allowed us to remove the employee from the blasting atmosphere into a control room. We have, and will continue to realize, significant environmental and economic savings by using PMB. Hill is also actively involved with the development of future paint stripping technologies.

Large Aircraft Robotic Paint Stripping (LARPS) system and the high pressure water process
94N10623
SEE, DAVID W.; HOFACKER, SCOTT A.; STONE, M. ANTHONY; HARBAUGH, DARCY (United Technologies Corp., Huntsville, AL.); (United Technologies Corp., Huntsville, AL.); (United Technologies Corp., Huntsville, AL.) In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 21 pages Avail: CASI HC A03/MF A02
The aircraft maintenance industry is beset by new Environmental Protection Agency (EPA) guidelines on air emissions, Occupational Safety and Health Administration (OSHA) standards, dwindling labor markets, Federal Aviation Administration (FAA) safety guidelines, and increased operating costs. In light of these factors, the USAF's Wright Laboratory Manufacturing Technology Directorate and the Aircraft Division of the Oklahoma City Air Logistics Center initiated a MANTECH/REPTECH effort to automate an alternate paint removal method and eliminate the current manual methylene chloride chemical stripping methods. This paper presents some of the background and history of the LARPS program, describes the LARPS system, documents the projected operational flow, quantifies some of the projected system benefits and describes the High Pressure Water Stripping Process. Certification of an alternative paint removal method to replace the current chemical process is being performed in two phases: Process Optimization and Process Validation. This paper also presents the results of the Process Optimization for metal substrates. Data on the coating removal rate, residual stresses, surface roughness,

preliminary process envelopes, and technical plans for process Validation Testing will be discussed.

Automated Laser Paint Stripping (ALPS) update
94N10624
LOVOI, PAUL In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 12 pages Avail: CASI HC A03/MF A02
To date, the DoD has played a major role in funding a number of paint stripping programs. Some technologies have proven less effective than contemplated. Others are still in the validation phase. Paint stripping is one of the hottest issues being addressed by the finishing industry since the Environmental Protection Agency (EPA) has mandated that chemical stripping using methylene chloridphenolic type strippers be stopped. The DoD and commercial aircraft companies are hard-pressed to find an alternative. Automated laser paint stripping has been identified as a technique for removing coatings from aircraft surfaces. International Technical Associates (InTA) was awarded a Navy contract for an automated laser paint stripping system (ALPS) that will remove paint from metallic and composite substrates. For the program, which will validate laser paint stripping, InTA will design, build, test, and install a system for fighter-sized aircraft at both the Norfolk and North Island (San Diego) Aviation Depots.

Aquastrip™: An innovative paint removal technology
94N10625
VOLKMAR, J. In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 10 pages Avail: CASI HC A02/MF A02
Environmental, safety and health issues, forced operators to search for an alternative paint removal process. High pressure water jetting and new integrated paint and stripper systems are Lufthansa's answer to this challenge. AQUASTRIP complies with the specification requirements. In order to receive approval from airframe manufacturers and authorities the process has undergone an extensive research program since 1988. An operation window was established, to enable maximum of safety during operation on metal and composite surfaces. Even though AQUASTRIP is a hybrid process and requires technological investment, it is well on the way to prove its innovative, ecological and economical character in first large scale applications under realistic conditions. Its potential has already been reflected by patents and trademarks, which were registered in conjunction with the development of AQUASTRIP and the vital interest for cooperative work on the process development and other potential utilization.

Paint removal and surface cleaning using ice particles
94N10626
FOSTER, TERRY; VISAISOUK, S. (Ice Blast International Corp., Victoria, British Columbia.) In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 10 pages Avail: CASI HC A02/MF A02
Research into the possibility of using ice particles as a blast medium was first initiated at Defence Research Establishment Pacific (DREP) in an effort to develop a more environmentally acceptable paint removal method. A paint removal process was also required that could be used in areas where normal grit blasting could not be used due to the possibility of the residual blasting grit contaminating machinery and other equipment. As a result of this research a commercial ice blasting system was developed by RETECH. This system is now being used to remove paint from substrates that cannot be easily blasted by conventional techniques and also to clean soiled or contaminated surfaces. The problems involved in the development of an ice blast system, and its components and their functions are described. Due to the complexity of paint removal using ice blasting, parameters such as air pressure, ice particle size and ice particle flow rate were studied and adjusted to suit the nature of the particular coating and substrate of interest. The mechanism of paint removal by ice particles has also been investigated. A theoretical model has been developed to explain the different paint removal mechanisms such as erosion by abrasion and erosion by fracture as they relate to ice blasting. Finally, the use of ice blasting to removal paint from a variety of substrates is presented as well as examples of surface cleaning and surface decontamination.

Paint removal using wheat starch blast media
94N10627
FOSTER, TERRY; OESTREICH, JOHN (Ogilvie Mills Ltd., Montreal, Quebec.) In AGARD, Environmentally Safe and Effective Processes for Paint Removal (SEE N94-10613 01-31) 9 pages Avail: CASI HC A02/MF A02
A review of the Wheat Starch Blasting technology is presented. Laboratory evaluations covering Almen Arc testing on bare 2024-T3 aluminum and magnesium, as well as crack detection on 7075-T6 bare aluminum, are discussed. Comparisons with Type V plastic media show lower residual stresses are achieved on aluminum and magnesium with wheat starch media. Dry blasting effects on the detection of cracks confirms better crack visibility with wheat starch media versus Type V or Type II plastic media. Testing of wheat starch media in several composite test programs, including fiberglass, Kevlar, and graphite-epoxy composites, showed no fiber damage. Process developments and production experience at the first U.S. aircraft stripping facility are also reviewed. Corporate and regional aircraft are being stripped in this three nozzle dry blast hangar.

IATA TaskForce: Paintstripping
94N10628
MOOY, THOMAS In AGARD, Environmentally Safe and Effective Processes for Paint Removal 5 p (SEE N94-10613 01-31) 5 pages Avail: CASI HC A01/MF A02
In 1990 the International Air Transport Association

(IATA) established a task force to stimulate the development of alternatives for chemical stripping of commercial aircraft. The IATA TaskForce Paintstripping objectives are: to identify the most promising, current alternatives for short term implementation; to prepare a document containing requirements for the development of alternatives; to stimulate the information exchange. After the September 1992 meeting the TaskForce will report back to IATA. The most tangible result of the TaskForce is the IATA Guidelines containing requirements for the qualification of stripping processes.

Selectively strippable paint schemes
94N10629
STEIN, R.; THUMM, D.; BLACKFORD, ROGER W. (Imperial Chemical Industries Ltd., Slough, England.) In AGARD, Environmentally Safe and Effective Processes for Paint Removal 4 p (SEE N94-10613 01-31) 4 pages Avail: CASI HC A01/MF A02
In order to meet the requirements of more environmentally acceptable paint stripping processes many different removal methods are under evaluation. These new processes can be divided into mechanical and chemical methods. ICI has developed a paint scheme with intermediate coat and fluid resistant polyurethane topcoat which can be stripped chemically in a short period of time with methylene chloride free and phenol free paint strippers.

Dry stripping as a surface treatment method
94N17544
NIEMINEN, ILKKA Sponsored by Finnish Industry, and Technical Research Centre of Finland, Espoo 72 pages Avail: CASI HC A04/MF A01
High environmental and safety standards as well as use of new paint and substrate materials have created the need for developing stripping methods to substitute chemical and mechanical methods and on the other hand for expanding the applicability of blasting as a surface treatment. Plastic Media Blasting (PMB) (alternatively Dry Stripping System (DSS)) is an emerging technology first used in aircraft maintenance for paint stripping. Traditionally this task is performed by brushing and grinding or by using chemical solvents. With plastic media it is possible to remove thick paints with high adhesion without damaging the substrate and even layer by layer. If suitable type of plastic media, blasting pressure low enough, media concentration high enough and on the other right blasting time, blasting distance and blasting angle are chosen, the effectiveness of PMB can be varied to a large extent. In regard to the hardness of media plastic particles are situated between some organic materials and shots used in sand blasting. Therefore composite materials can be treated without damaging the substrate or thin metal plates without causing any deformations. The principle of plastic media blasting equipment is similar to traditional blasting equipment. Nevertheless the properties of plastic media are different to harder particles used in shot peening resulting in higher demands for filtration, ventilation and recycling systems. In addition the facilities have to contain proper recovery equipment, because plastic media can be reused, even 20 times. In recycling systems plastic media is cleaned, too large and too small particles are removed, hard and magnetic particles are removed from reusable media and dust is separated from media. In addition to paint stripping PMB can successfully be used for cleaning of surfaces from contamination and to some extent for polishing, grinding and roughening. Paint stripping has been the main application so far, but there may be many other possibilities to apply the method in the future. However the PMB is not the only new technology for stripping problems. Some interesting investigations were performed for using frozen carbon dioxide, soda or high pressure water jet for paint stripping.

Effects of plastic media blasting on aircraft skin
94N26488
CHEN, CHARLES C.; MULLER, MARK; REINHARDT, JOHN W. 113 pages Avail: CASI HC A06/MF A02
The use of methylene chloride chemical solvents in aviation paint removal is becoming increasingly unacceptable in view of restrictive Environmental Protection Agency (EPA) regulations. A readily available alternative, plastic media blasting (PMB), must be examined for its effects on the thin aluminum used as skin material in civilian aircraft. This study examines the effects of plastic media blasting or the crack propagation rates of 2024-T3 aluminum in alclad of 0.032, 0.040, 0.050 inch thickness, and in anodized of 0.032, 0.040, and 0.050 inch thickness. A technical search was performed for the following topics: (1) fatigue crack growth (FCG) rate comparison between PMB and chemical stripping, (2) effects of heavy particulate contamination on the fatigue life of aircraft skin, (3) acceptable level of contamination in the plastic media, (4) effects of multiple strippings on FCG, (5) maximum number of strippings allowed, and (6) specifications of controlled parameters to safely operate a PMB system. Fatigue crack propagation tests, Almen strip tests, Scanning Electron Microscope (SEM) photography, and surface toughness measurements were conducted. The results of the technical search and the tests performed are presented, as well as supplementary Almen strip arc height data. This study also presents an overview of nine alternative aviation paint stripping methods in terms of paint stripping effectiveness, substrate damage, environmental impact, health impact, and cost.

The effect of mechanical paint stripping on the fatigue and fracture of thin aluminum airplane skin
94N29900
AMRO, JOE P. 150 pages Avail: Univ. Microfilms Order No. DA9311975
An experimental investigation has been carried out to evaluate the affects of dry stripping (paint removal by plastic particle blasting) on aluminum aircraft skins (2024-T3). Analytical procedures were carried out for determining changes in fatigue life and relevant

fracture resistance parameters such as number of cycles required to generate a surface crack of certain length, crack propagation rate, and number of cycles to failure while indicating the dependence of these parameters on the surface condition (morphology). The surface morphology dependence on deformation, fracture resistance properties, and defects presented on the surface were characterized using scanning electron microscopy, optical microscopy, and other modern metallographic techniques. The results indicated that all the parameters of plastic media blasting had significant effects on the fatigue life of the specimens. Minor changes in the blasting parameters may reveal different results. All fatigue samples were found to exhibit a general decrease in life of 10 to 46 percent after being subjected to four cycles of paint removal. The samples were cyclically loaded to 20,000 cycles then stripped and repainted four times; 20,000 cycles represents approximately 5 years of life. The initial stress ratio for loading was 0.1 with stresses varying from 20 to 65 ksi.

Evaluation of corrosion protecting properties of modern aircraft paint systems
94N30420
THART, W. G. J.; BOOGERS, J. A. M. Presented at the Aerospace Corrosion Control Symposium, Amsterdam, Netherlands, 23-25 Mar. 1992
Sponsored by Royal Netherlands Air Force 32 pages
Avail: CASI HC A03
The flexibility, adhesion and corrosion protecting properties of several modern paint systems were examined. Since paint cracking around fasteners under operational conditions usually occurs at low temperatures, this was examined by tensile testing of painted metal strips at -50C. After tensile testing the degree of paint delamination (loss of adhesion) was established, and cross sections were made to examine this delamination on a microscopic scale. The corrosion protecting capability of paint systems was determined by exposing specimens with a precracked paint system and crossed scribe lines to an accelerated corrosion test (MASTMAASIS). In this investigation the different paint systems had the same topcoat, Aerodur HF A 132. Since Plastic Media Blasting (PMB) is a potential method for replacing the chemical paint stripping procedure, PMB and various cleaning operations were also considered.

Fatigue testing of 2024-T3 material after four cycles of PMB stripping
94N32237
58 pages Avail: CASI HC A04/MF A01
The goal of this program was to determine the effect of plastic media blasting (PMB), an alternative to chemical paint removal, on the fatigue life of 2024-T3 aluminum. Two surface treatments, anodized and alclad, of three thicknesses: 0.032 inch, 0.040 inch, and 0.050 inch were considered. A number of alclad and anodized aluminum panels of the alloy and thicknesses specified were subjected to four cycles of PMB. The blast parameters were identical to those used in a previous FAA program. Almen strips tests were performed to quantify the blast intensity. A fatigue testing program was conducted on both the 'as received' and the PMB treated material. Reductions in mean fatigue life were observed for all materials tested after PMB treatment. These reductions were statistically significant for the 0.032 alclad and 0.040 anodized specimens.

Diode array alternative to paint removal solid-state cw laser
94N37203
COMASKEY, BRIAN 5 pages Avail: CASI HC A01/MF A01
The purpose of this memo is to highlight an alternative to the approach for cw laser paint removal. The point to be made is that a direct diode design is feasible and can be far more competitive than a solid-state laser based system. Through by-passing the use of a solid-state laser media, we immediately gain a factor of about five in system efficiency based on measured optical-to-optical efficiencies of our average power diode pumped lasers. This permits a massive reduction in system cooling requirements. It should be noted that cooling system size was the greatest concern voiced by Gordon McFadden at Hobart Lasers with regards to his Nd:YAG laser systems operated in field applications. Furthermore, with direct diode use far fewer diode packages will be needed to deliver a given amount of wattage on the target. This will largely eliminate the intimidating sticker shock and shorten (proportionally by the diode count) the required run-to-fail times demanded of the system.

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-LS-201	ISBN 92-836-1017-2	UNCLASSIFIED/ UNLIMITED

5. Originator Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly-sur-Seine, France

6. Title
Environmentally Safe and Effective Processes
for Paint Removal

7. Presented at/sponsored by
27-28 April 1995 in Lisbon, Portugal,
1-2 May 1995 in Eskisehir, Turkey, and
4-5 May 1995 in Ottobrunn, Germany

8. Author(s)/Editor(s)	9. Date
Various	April 1995

10. Author's/Editor's Address	11. Pages
Various	104

12. Distribution Statement There are no restrictions on the distribution of this document. Information about the availability of this and other AGARD unclassified publications is given on the back cover.

13. Keywords/Descriptors

Paint removers	Ice particle blasting
Abrasives	Dry ice
Paint stripping	Laser applications
Cleaning agents	Evaluation
Plastic media blasting	Environmental impact
Starch media blasting	Waste treatment
Wheat	Biodegradation
Water blasting	

14. Abstract

Paint stripping and repainting of aircraft surfaces are required periodically during the operating lifetime of an aircraft. Historically, paint removal has been achieved using chemical strippers, involving materials which contain toxic components and which create hazardous working conditions. The process generates large amounts of hazardous waste from the chemicals used. Alternative methods for aircraft paint removal are now being investigated within the NATO nations with regard to their environmental safety and effective application. These processes include: Plastic Media Blasting, Wheat Starch Dry Media Blasting, Carbon Dioxide Pellet Blasting, Sodium Bicarbonate Blasting and Thermal Decomposition Methods (Laser, Flash Lamps/Carbon Dioxide). The Lecture Series will review these current state-of-the-art alternative methods with regard to environmental effects and related health hazards, costs, process controls, practicality of operation and their effects on properties of aircraft structural materials.

AGARD

NATO - OTAN

7 RUE ANCELLE • 92200 NEUILLY-SUR-SEINE

FRANCE

Télécopie (1)47.38.57.99 • Télex 610 176

DIFFUSION DES PUBLICATIONS

AGARD NON CLASSIFIEES

Aucun stock de publications n'a existé à AGARD. A partir de 1993, AGARD détiendra un stock limité des publications associées aux cycles de conférences et cours spéciaux ainsi que les AGARDographies et les rapports des groupes de travail, organisés et publiés à partir de 1993 inclus. Les demandes de renseignements doivent être adressées à AGARD par lettre ou par fax à l'adresse indiquée ci-dessus. *Veuillez ne pas téléphoner*. La diffusion initiale de toutes les publications de l'AGARD est effectuée auprès des pays membres de l'OTAN par l'intermédiaire des centres de distribution nationaux indiqués ci-dessous. Des exemplaires supplémentaires peuvent parfois être obtenus auprès de ces centres (à l'exception des Etats-Unis). Si vous souhaitez recevoir toutes les publications de l'AGARD, ou simplement celles qui concernent certains Panels, vous pouvez demander à être inclu sur la liste d'envoi de l'un de ces centres. Les publications de l'AGARD sont en vente auprès des agences indiquées ci-dessous, sous forme de photocopie ou de microfiche.

CENTRES DE DIFFUSION NATIONAUX

ALLEMAGNE
Fachinformationszentrum,
Karlsruhe
D-76344 Eggenstein-Leopoldshafen 2

BELGIQUE
Coordonnateur AGARD-VSL
Etat-major de la Force aérienne
Quartier Reine Elisabeth
Rue d'Evere, 1140 Bruxelles

CANADA
Directeur, Services d'information scientifique
Ministère de la Défense nationale
Ottawa, Ontario K1A 0K2

DANEMARK
Danish Defence Research Establishment
Ryvangs Allé 1
P.O. Box 2715
DK-2100 Copenhagen Ø

ESPAGNE
INTA (AGARD Publications)
Pintor Rosales 34
28008 Madrid

ETATS-UNIS
NASA Headquarters
Code JOB-1
Washington, D.C. 20546

FRANCE
O.N.E.R.A. (Direction)
29, Avenue de la Division Leclerc
92322 Châtillon Cedex

GRECE
Hellenic Air Force
Air War College
Scientific and Technical Library
Dekelia Air Force Base
Dekelia, Athens TGA 1010

ISLANDE
Director of Aviation
c/o Flugrad
Reykjavik

ITALIE
Aeronautica Militare
Ufficio del Delegato Nazionale all'AGARD
Aeroporto Pratica di Mare
00040 Pomezia (Roma)

LUXEMBOURG
Voir Belgique

NORVEGE
Norwegian Defence Research Establishment
Attn: Biblioteket
P.O. Box 25
N-2007 Kjeller

PAYS-BAS
Netherlands Delegation to AGARD
National Aerospace Laboratory NLR
P.O. Box 90502
1006 BM Amsterdam

PORTUGAL
Força Aérea Portuguesa
Centro de Documentação e Informação
Alfragide
2700 Amadora

ROYAUME-UNI
Defence Research Information Centre
Kentigern House
65 Brown Street
Glasgow G2 8EX

TURQUIE
Millî Savunma Başkanliği (MSB)
ARGE Dairesi Başkanliği (MSB)
06650 Bakanliklar-Ankara

Le centre de distribution national des Etats-Unis ne détient PAS de stocks des publications de l'AGARD.

D'éventuelles demandes de photocopies doivent être formulées directement auprès du NASA Center for AeroSpace Information (CASI) à l'adresse ci-dessous. Toute notification de changement d'adresse doit être fait également auprès de CASI.

AGENCES DE VENTE

NASA Center for
AeroSpace Information (CASI)
800 Elkridge Landing Road
Linthicum Heights, MD 21090-2934
Etats-Unis

ESA/Information Retrieval Service
European Space Agency
10, rue Mario Nikis
75015 Paris
France

The British Library
Document Supply Division
Boston Spa, Wetherby
West Yorkshire LS23 7BQ
Royaume-Uni

Les demandes de microfiches ou de photocopies de documents AGARD (y compris les demandes faites auprès du CASI) doivent comporter la dénomination AGARD, ainsi que le numéro de série d'AGARD (par exemple AGARD-AG-315). Des informations analogues, telles que le titre et la date de publication sont souhaitables. Veuiller noter qu'il y a lieu de spécifier AGARD-R-nnn et AGARD-AR-nnn lors de la commande des rapports AGARD et des rapports consultatifs AGARD respectivement. Des références bibliographiques complètes ainsi que des résumés des publications AGARD figurent dans les journaux suivants:

Scientific and Technical Aerospace Reports (STAR)
publié par la NASA Scientific and Technical
Information Division
NASA Headquarters (JTT)
Washington D.C. 20546
Etats-Unis

Government Reports Announcements and Index (GRA&I)
publié par le National Technical Information Service
Springfield
Virginia 22161
Etats-Unis
(accessible également en mode interactif dans la base de données bibliographiques en ligne du NTIS, et sur CD-ROM)

Imprimé par le Groupe Communication Canada
45, boul. Sacré-Cœur, Hull (Québec), Canada K1A 0S7

AGARD

NATO - OTAN

7 RUE ANCELLE • 92200 NEUILLY-SUR-SEINE

FRANCE

Telefax (1)47.38.57.99 • Telex 610 176

DISTRIBUTION OF UNCLASSIFIED AGARD PUBLICATIONS

AGARD holds limited quantities of the publications that accompanied Lecture Series and Special Courses held in 1993 or later, and of AGARDographs and Working Group reports published from 1993 onward. For details, write or send a telefax to the address given above. *Please do not telephone.*

AGARD does not hold stocks of publications that accompanied earlier Lecture Series or Courses or of any other publications. Initial distribution of all AGARD publications is made to NATO nations through the National Distribution Centres listed below. Further copies are sometimes available from these centres (except in the United States). If you have a need to receive all AGARD publications, or just those relating to one or more specific AGARD Panels, they may be willing to include you (or your organisation) on their distribution list. AGARD publications may be purchased from the Sales Agencies listed below, in photocopy or microfiche form.

NATIONAL DISTRIBUTION CENTRES

BELGIUM
Coordonnateur AGARD — VSL
Etat-major de la Force aérienne
Quartier Reine Elisabeth
Rue d'Evere, 1140 Bruxelles

CANADA
Director Scientific Information Services
Dept of National Defence
Ottawa, Ontario K1A 0K2

DENMARK
Danish Defence Research Establishment
Ryvangs Allé 1
P.O. Box 2715
DK-2100 Copenhagen Ø

FRANCE
O.N.E.R.A. (Direction)
29 Avenue de la Division Leclerc
92322 Châtillon Cedex

GERMANY
Fachinformationszentrum
Karlsruhe
D-76344 Eggenstein-Leopoldshafen 2

GREECE
Hellenic Air Force
Air War College
Scientific and Technical Library
Dekelia Air Force Base
Dekelia, Athens TGA 1010

ICELAND
Director of Aviation
c/o Flugrad
Reykjavik

ITALY
Aeronautica Militare
Ufficio del Delegato Nazionale all'AGARD
Aeroporto Pratica di Mare
00040 Pomezia (Roma)

LUXEMBOURG
See Belgium

NETHERLANDS
Netherlands Delegation to AGARD
National Aerospace Laboratory, NLR
P.O. Box 90502
1006 BM Amsterdam

NORWAY
Norwegian Defence Research Establishment
Attn: Biblioteket
P.O. Box 25
N-2007 Kjeller

PORTUGAL
Força Aérea Portuguesa
Centro de Documentação e Informação
Alfragide
2700 Amadora

SPAIN
INTA (AGARD Publications)
Pintor Rosales 34
28008 Madrid

TURKEY
Millî Savunma Başkanliği (MSB)
ARGE Dairesi Başkanliği (MSB)
06650 Bakanliklar-Ankara

UNITED KINGDOM
Defence Research Information Centre
Kentigern House
65 Brown Street
Glasgow G2 8EX

UNITED STATES
NASA Headquarters
Code JOB-1
Washington, D.C. 20546

The United States National Distribution Centre does NOT hold stocks of AGARD publications.
Applications for copies should be made direct to the NASA Center for AeroSpace Information (CASI) at the address below.
Change of address requests should also go to CASI.

SALES AGENCIES

NASA Center for
AeroSpace Information (CASI)
800 Elkridge Landing Road
Linthicum Heights, MD 21090-2934
United States

ESA/Information Retrieval Service
European Space Agency
10, rue Mario Nikis
75015 Paris
France

The British Library
Document Supply Centre
Boston Spa, Wetherby
West Yorkshire LS23 7BQ
United Kingdom

Requests for microfiches or photocopies of AGARD documents (including requests to CASI) should include the word 'AGARD' and the AGARD serial number (for example AGARD-AG-315). Collateral information such as title and publication date is desirable. Note that AGARD Reports and Advisory Reports should be specified as AGARD-R-nnn and AGARD-AR-nnn, respectively. Full bibliographical references and abstracts of AGARD publications are given in the following journals:

Scientific and Technical Aerospace Reports (STAR)
published by NASA Scientific and Technical
Information Division
NASA Headquarters (JTT)
Washington D.C. 20546
United States

Government Reports Announcements and Index (GRA&I)
published by the National Technical Information Service
Springfield
Virginia 22161
United States
(also available online in the NTIS Bibliographic
Database or on CD-ROM)

Printed by Canada Communication Group
45 Sacré-Cœur Blvd., Hull (Québec), Canada K1A 0S7

ISBN 92-836-1017-2